UCRL-PRES-234407

NIF Diagnostics

Presentation to
NIF Nuclear Astrophysics Workshop

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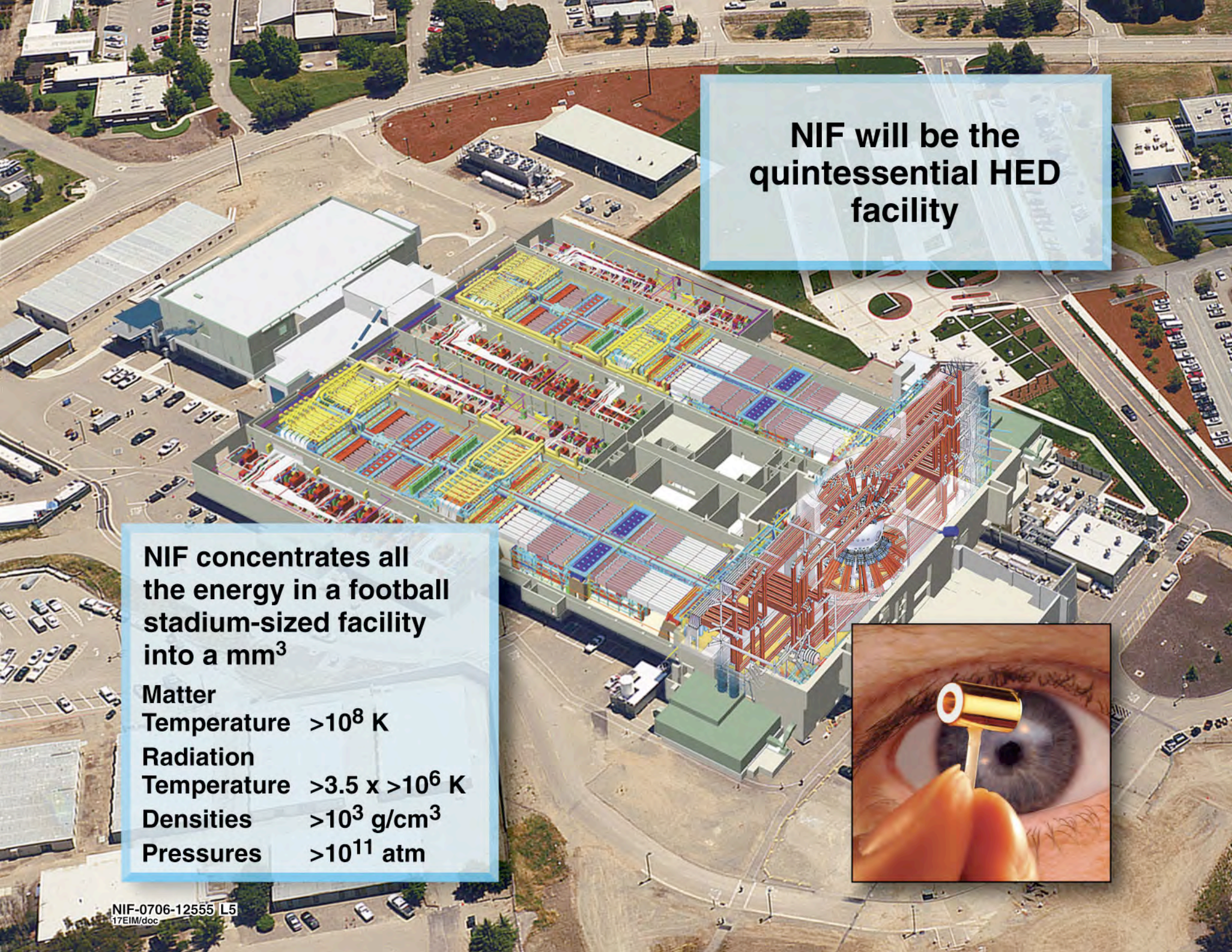
Lawrence Livermore National Laboratory

Aug. 28, 2007

Work performed under the auspices of the U.S. Department of Energy
by the University of California, Lawrence Livermore National Laboratory
under Contract No. W-7405-ENG-48.


NIF will be the quintessential HED facility
NIF concentrates all the energy in a football stadium-sized facility into a mm3
Matter Temperature >10^8 K
Radiation Temperature >3.5 x >10^6 K
Densities >10^3 g/cm^3
Pressures >10^11 atm
NIF-0706-12555 L5
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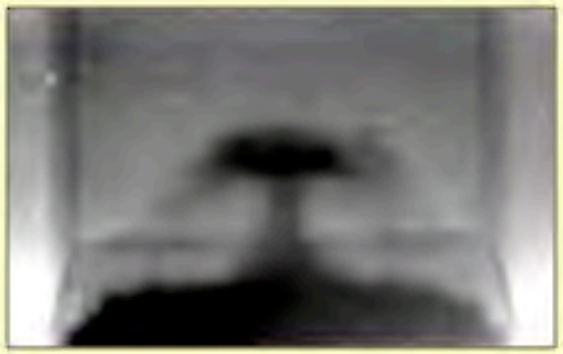
NIF will support three national research agendas

The National Ignition Facility

National Nuclear Security Administration

Stockpile Stewardship Program



Sandia National Laboratories

Los Alamos NATIONAL LABORATORY EST. 1943

National Ignition Campaign

Sandia National Laboratories

Los Alamos NATIONAL LABORATORY EST. 1943

GENERAL ATOMICS AND AFFILIATED COMPANIES

UNIVERSITY OF ROCHESTER

National Science Goals

NSF

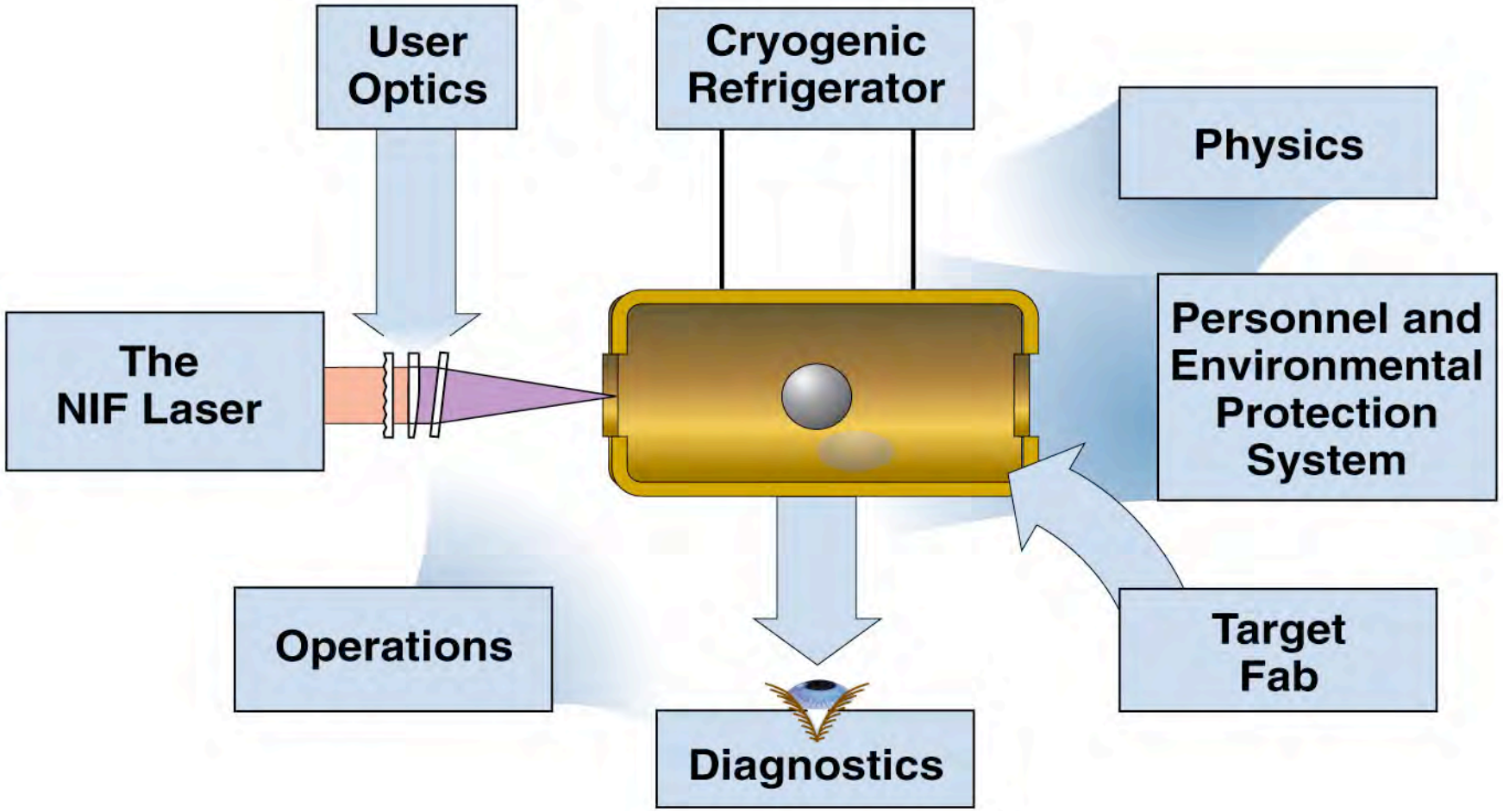
Washington State University

NASA

UNIVERSITY OF ROCHESTER

Capabilities developed for one mission will be also be available for the other users

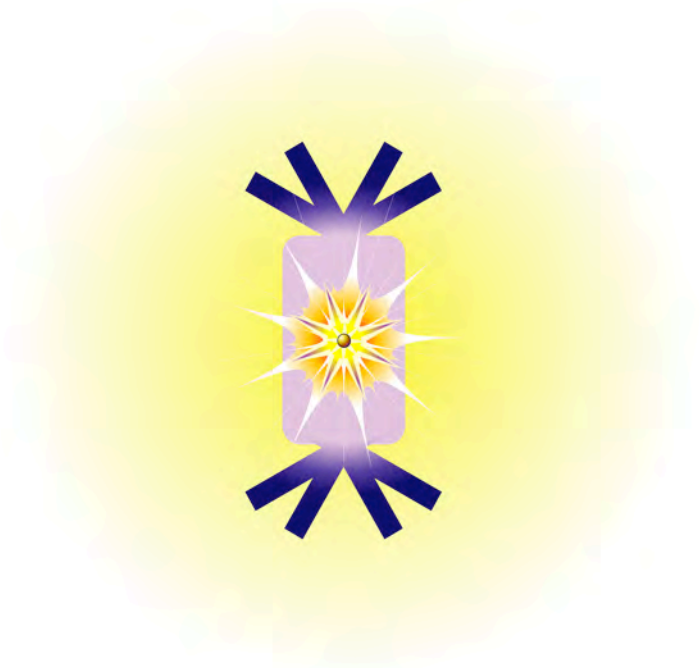
The National Ignition Facility



An extensive set of capabilities is being developed for the National Ignition Program

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

The National Ignition Facility



NIF-0405-10643 L1

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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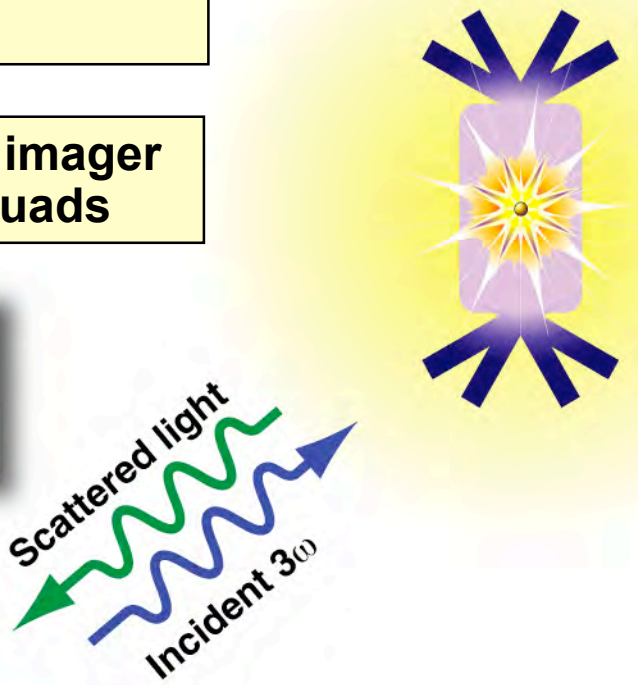
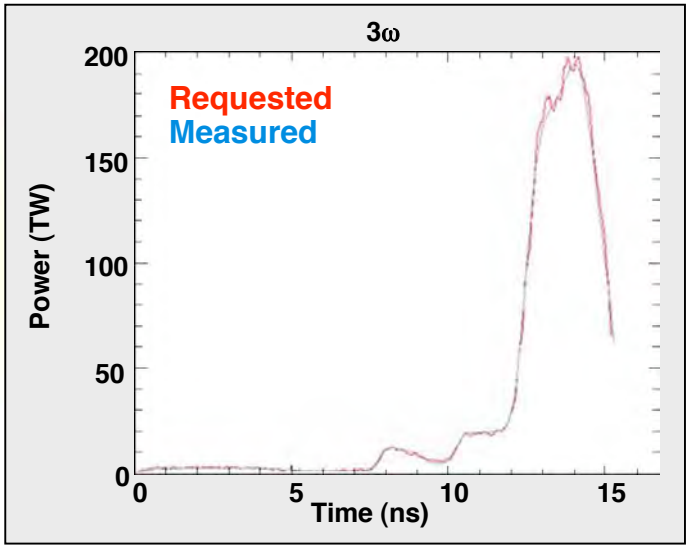
Optical Diagnostics are used for:
- **Energy Balance: Incident and scatteredlight**
- **Laser - Plasma Instabilities: Raman & Brillioun Spectra**

Full aperture backscatter diagnostic on 2 quads (Q36B, Q31B)

Near backscatter imager diagnostic on 2 quads

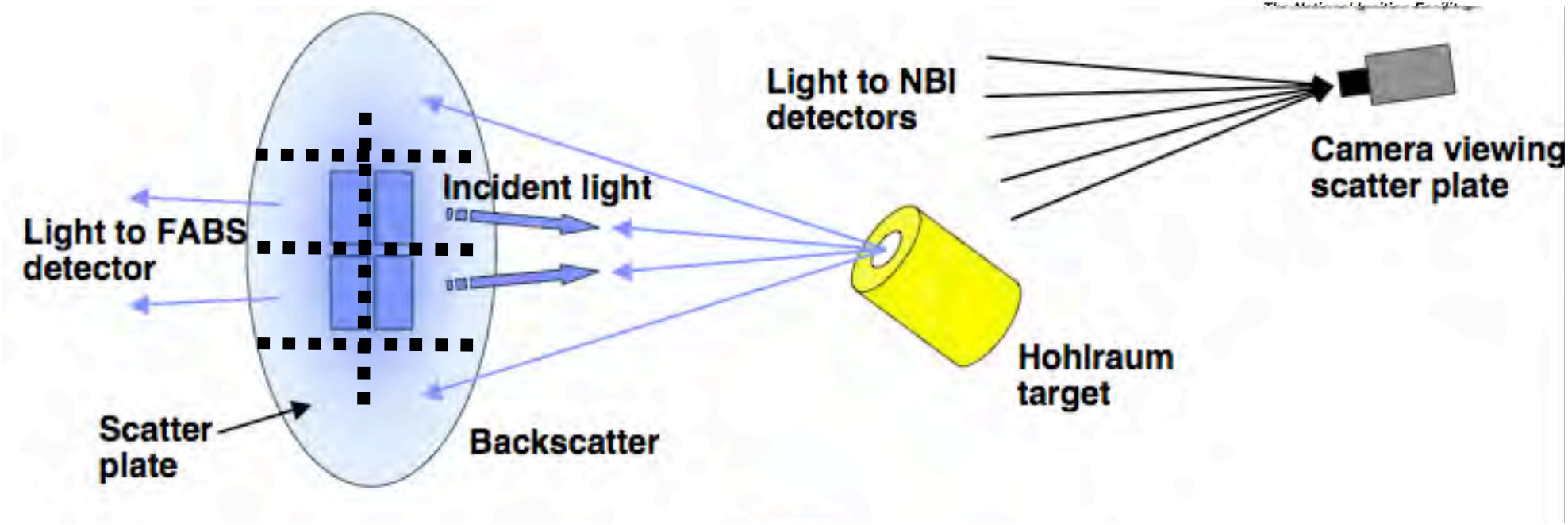
Optical Diagnostics





3ω energy diagnostic
3ω power diagnostic

FABS and NBI measures backscattered light on quads Q31B and Q36B



FABS (Full Aperture Backscatter System)	NBI (Near Backscatter Imager)
• Time resolved (100 psec) • Spectrally resolved — SBS .03 nm — SRS 6 nm	• Time integrated SRS and SBS • Space and time resolved SRS or SBS

Diagnostic capability for laser-plasma interaction experiments

FABS measures backscattered light through the lens transmitted through the final turning mirror

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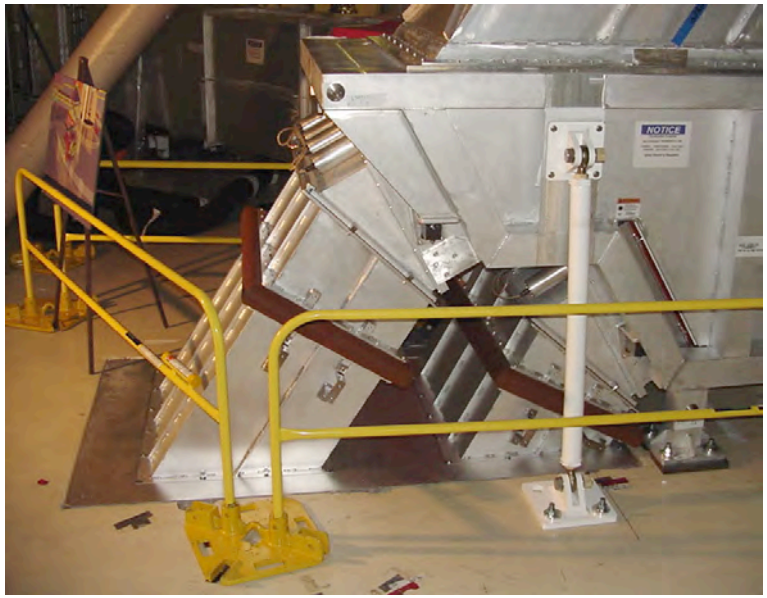
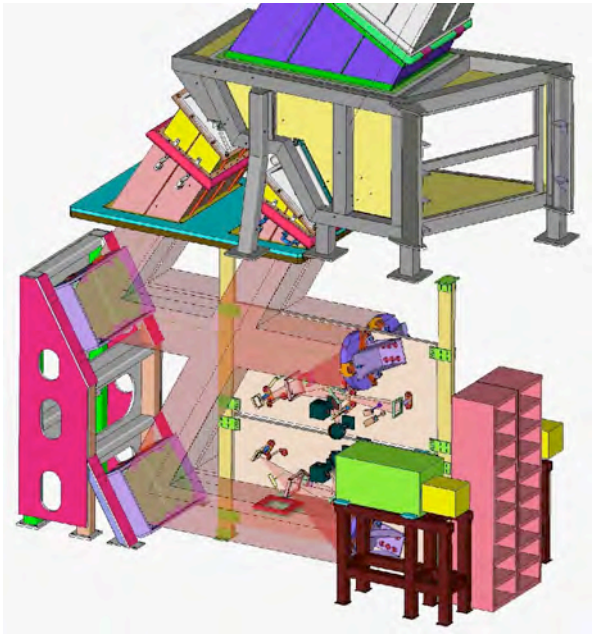
Full Aperture Backscatter System (FABS)



Scattered light through the lens



Schematic showing scattered light in FABS enclosure

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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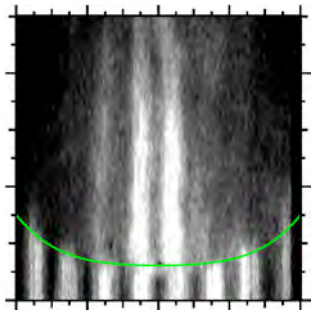
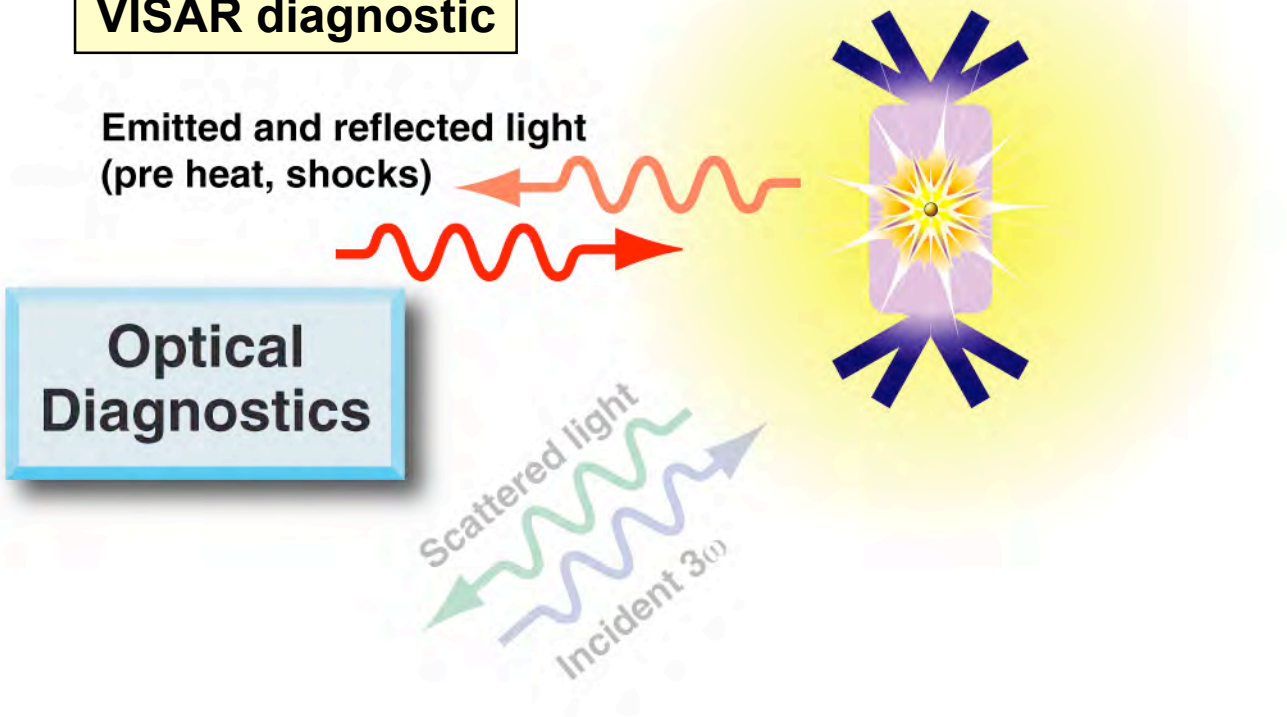
VISAR is a velocity interferometer for measuring reflections from shock waves and other surfaces



VISAR diagnostic



Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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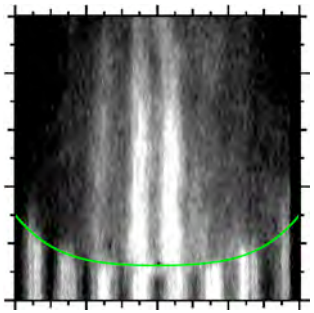


VISAR diagnostic

Emitted and reflected light
(pre heat, shocks)

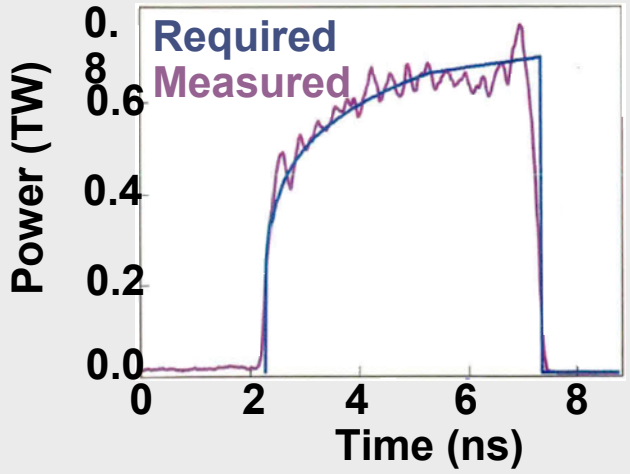
Optical Diagnostics

Scattered light

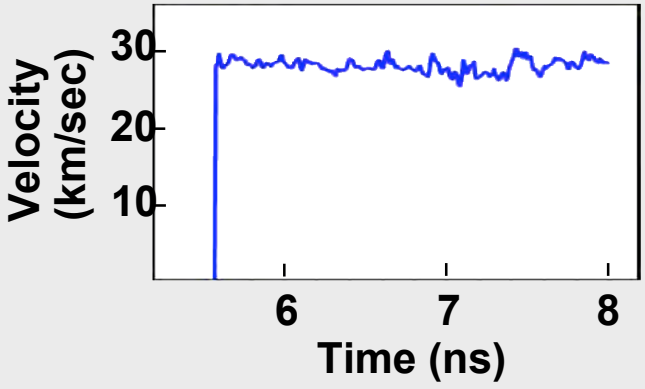
Incident 3ω

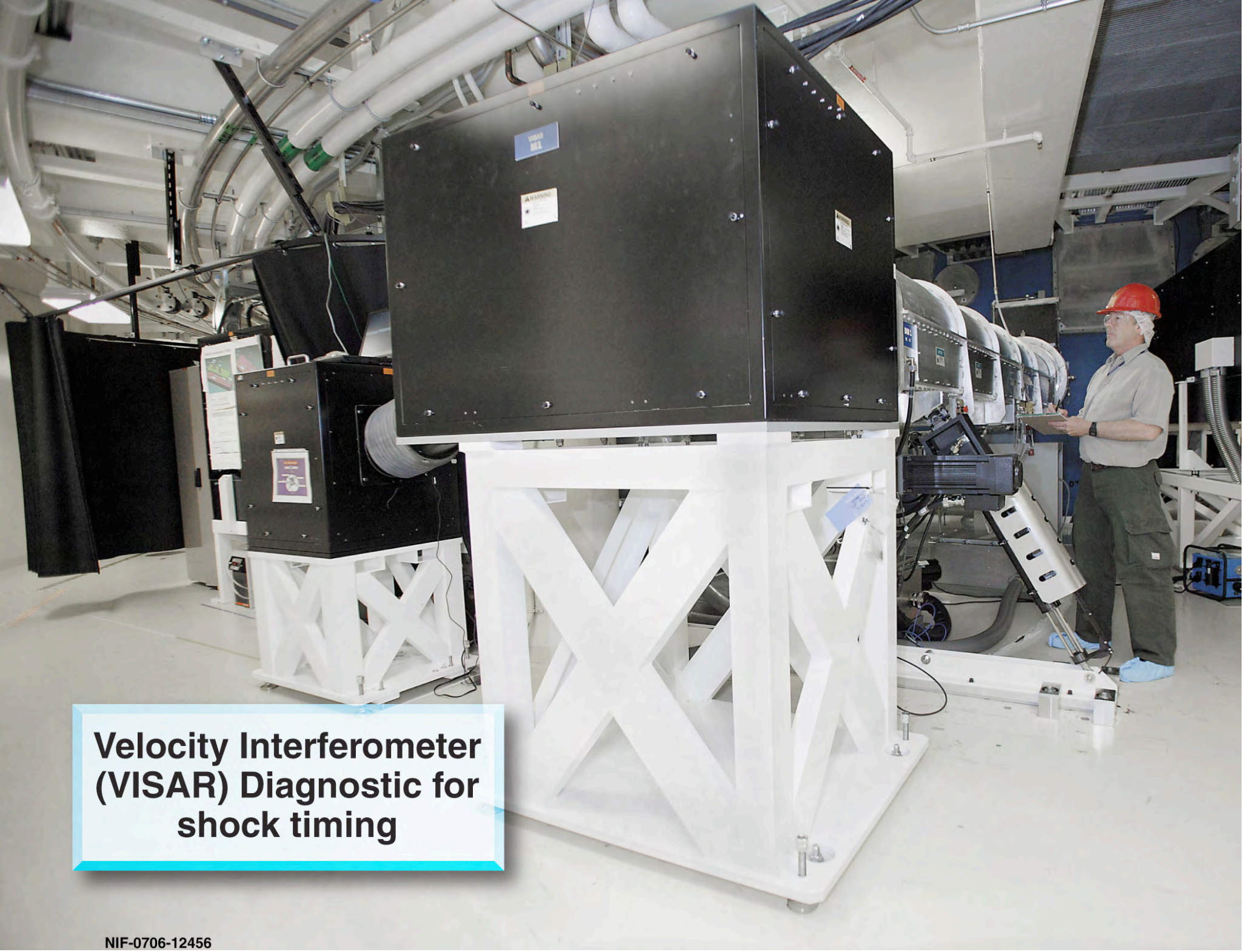
Diagnostic capability for shocked EOS experiments

Pulse shape for EOS



Accurate pulse shape results in a steady shock





Velocity Interferometer (VISAR) Diagnostic for shock timing

NIF-0706-12456

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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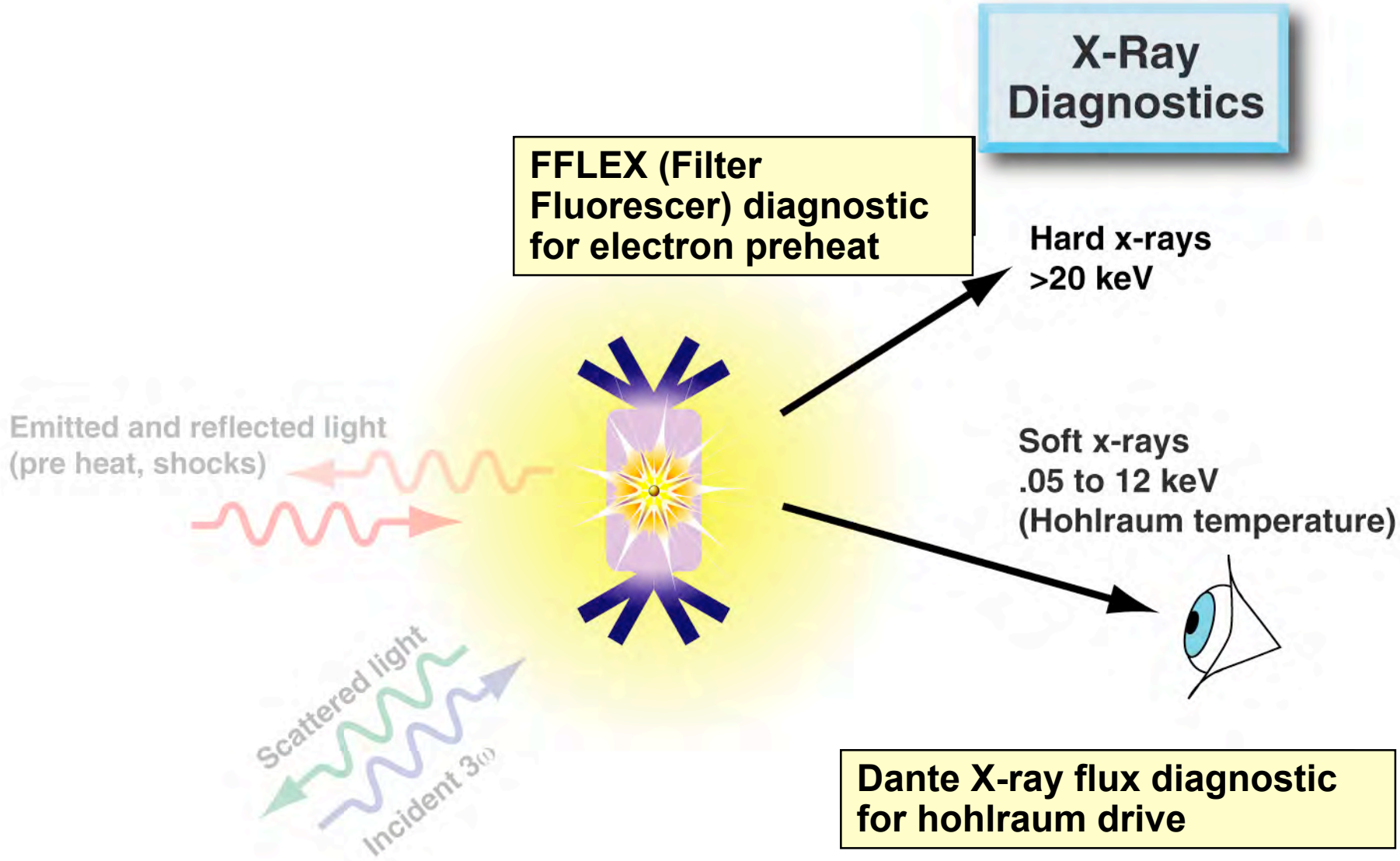

Diagnosing NIC experiments requires detection of different types of emissions ~ 100 psec, 100 μm

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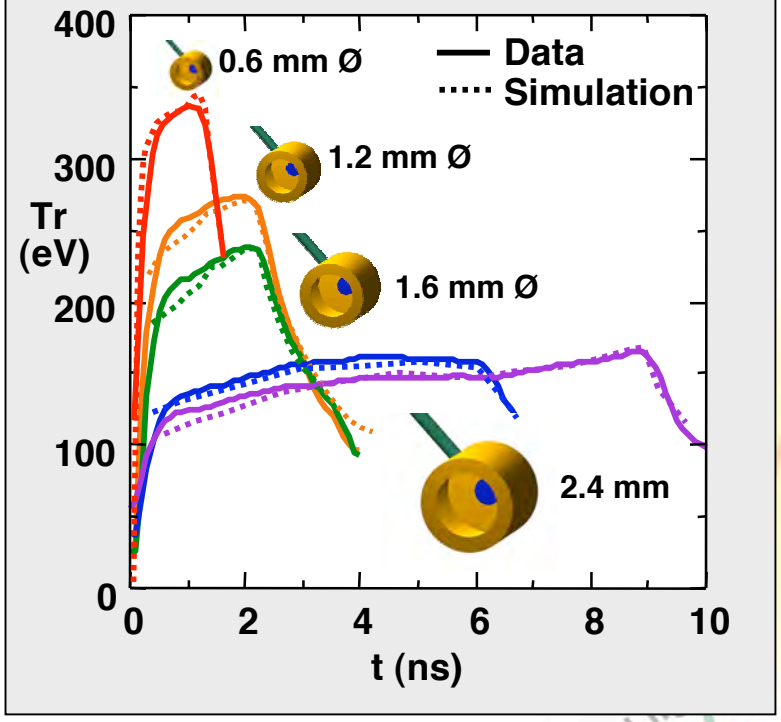
Hohlraum Temperature DANTE Data vs Simulations



X-Ray Diagnostics

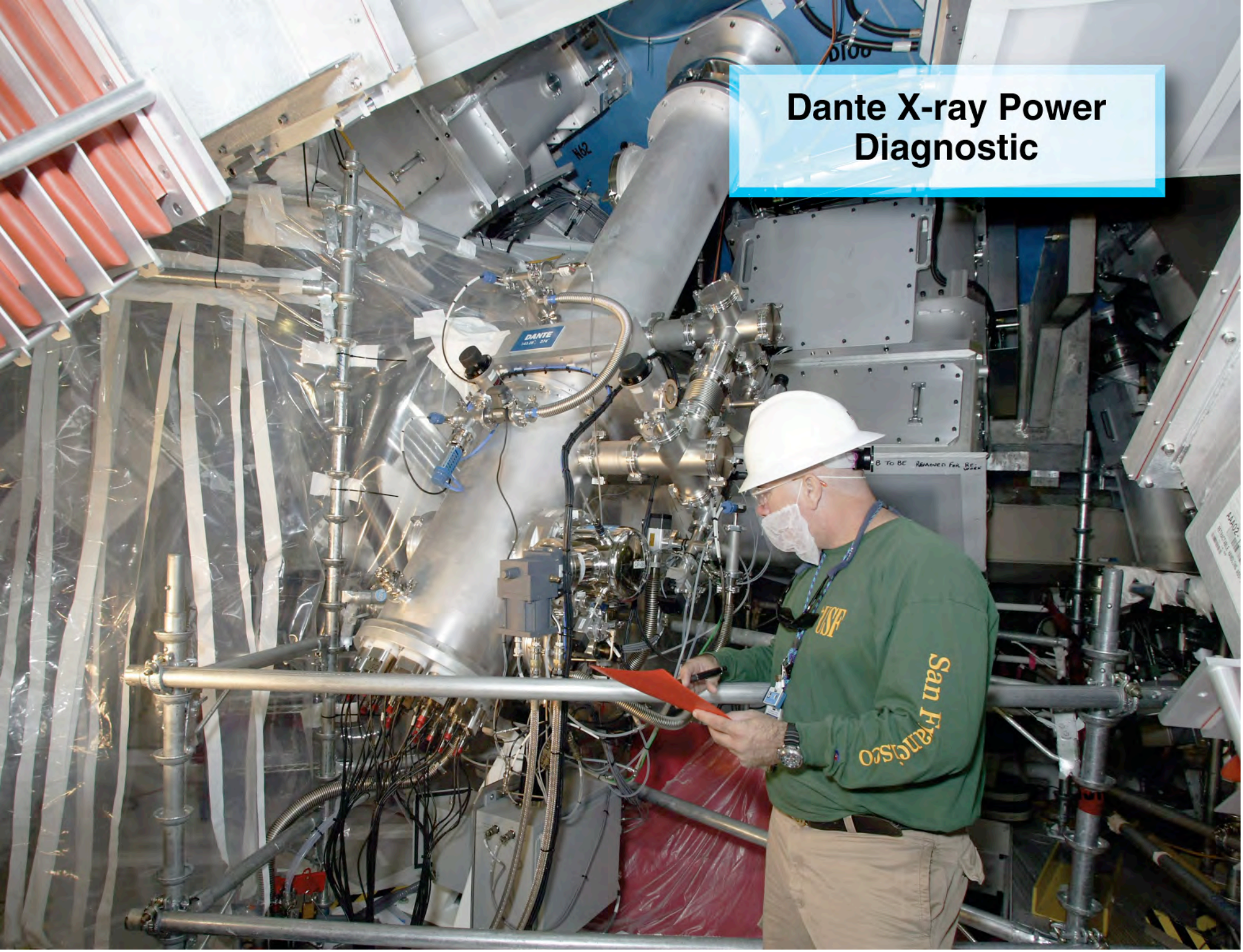
FFLEX (Filter Fluorescer) diagnostic for electron preheat

Hard x-rays
>20 keV

Soft x-rays
.05 to 12 keV
(Hohlraum temperature)

Dante X-ray flux diagnostic for hohlraum drive

Diagnostic capability for X-ray driven experiments


Dante X-ray Power
Diagnostic
DANTE
USF
San Francisco

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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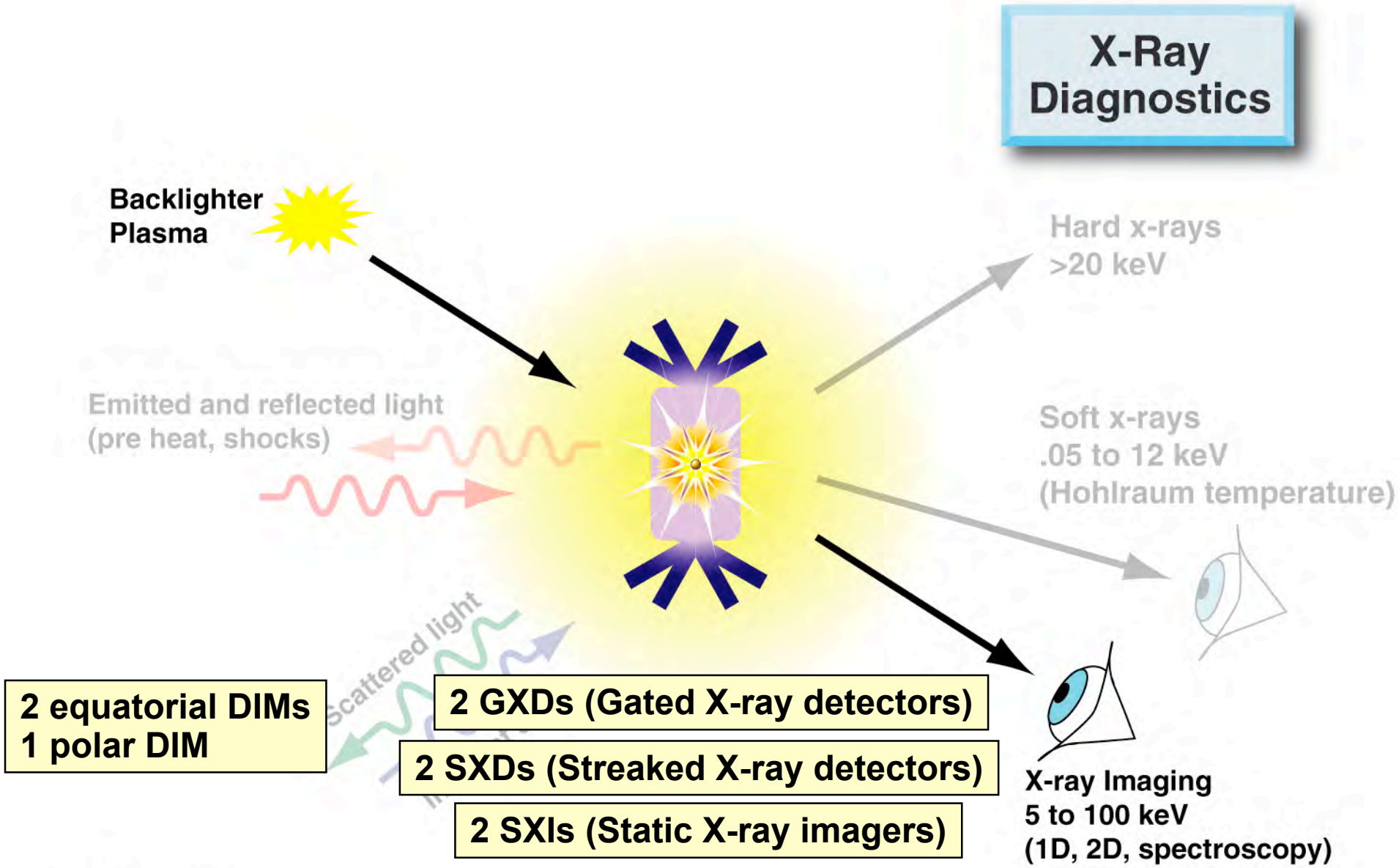

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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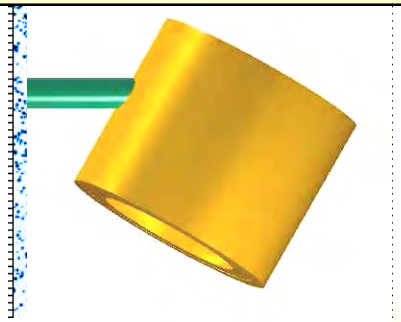
Hydrodynamic Jets

X-ray Drive in hohlraums



X-Ray Diagnostics

Backlighter Plasma

Hard x-rays >20 keV

Emitted and reflected light (pre heat, shocks)

Soft x-rays .05 to 12 keV (Hohlraum temperature)

Scattered light

2 equatorial DIMs
1 polar DIM

2 GXDs (Gated X-ray detectors)

2 SXDs (Streaked X-ray detectors)

2 SXIs (Static X-ray imagers)

X-ray Imaging
5 to 100 keV
(1D, 2D, spectroscopy)

Diagnostic capability for hydrodynamics, implosions, spectroscopy, LPI,…

There are Diagnostic Instrument Manipulators for inserting diagnostic systems into the chamber

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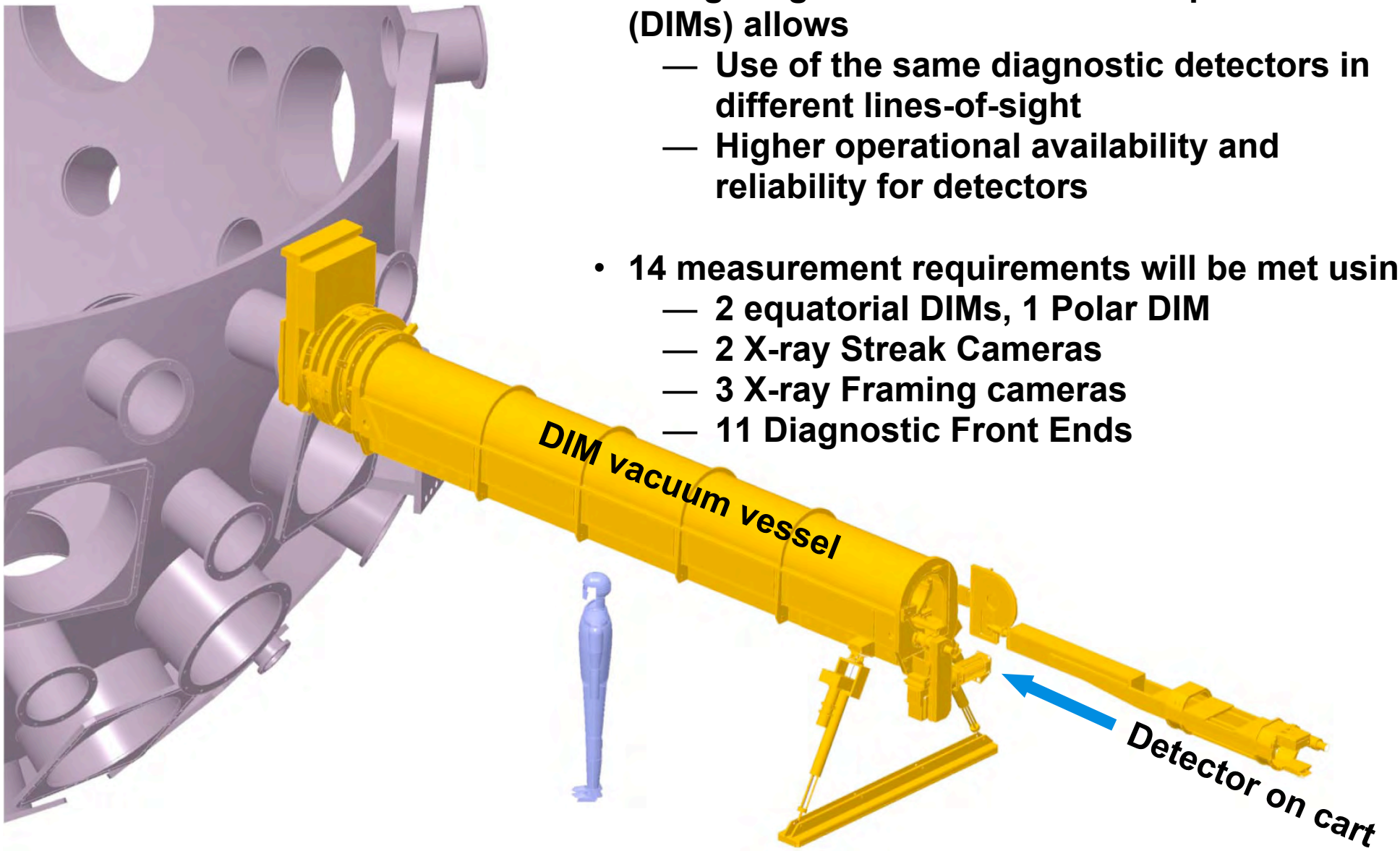
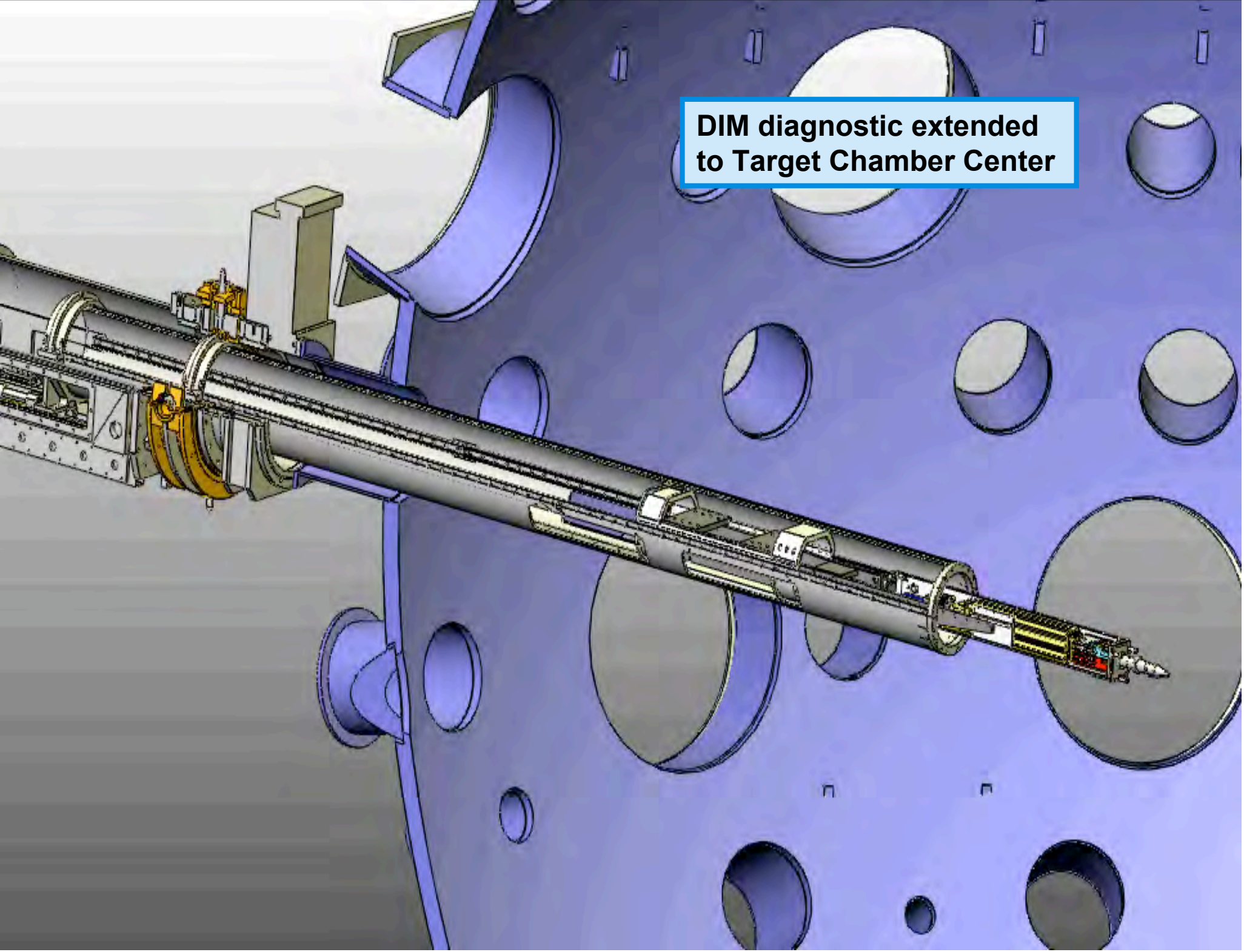
- Using Diagnostic Instrument Manipulators (DIMs) allows
  - Use of the same diagnostic detectors in different lines-of-sight
  - Higher operational availability and reliability for detectors

- 14 measurement requirements will be met using
  - 2 equatorial DIMs, 1 Polar DIM
  - 2 X-ray Streak Cameras
  - 3 X-ray Framing cameras
  - 11 Diagnostic Front Ends




DIM diagnostic extended
to Target Chamber Center

Two DIMs are commissioned
DIM
NIF-0305-10605rev1

First DIM Based X-Ray
Framing Camera in Air Box
NIF-0706-12454

Diagnosing NIC experiments requires detection of different types of emissions ~ 100 psec, 100 μm

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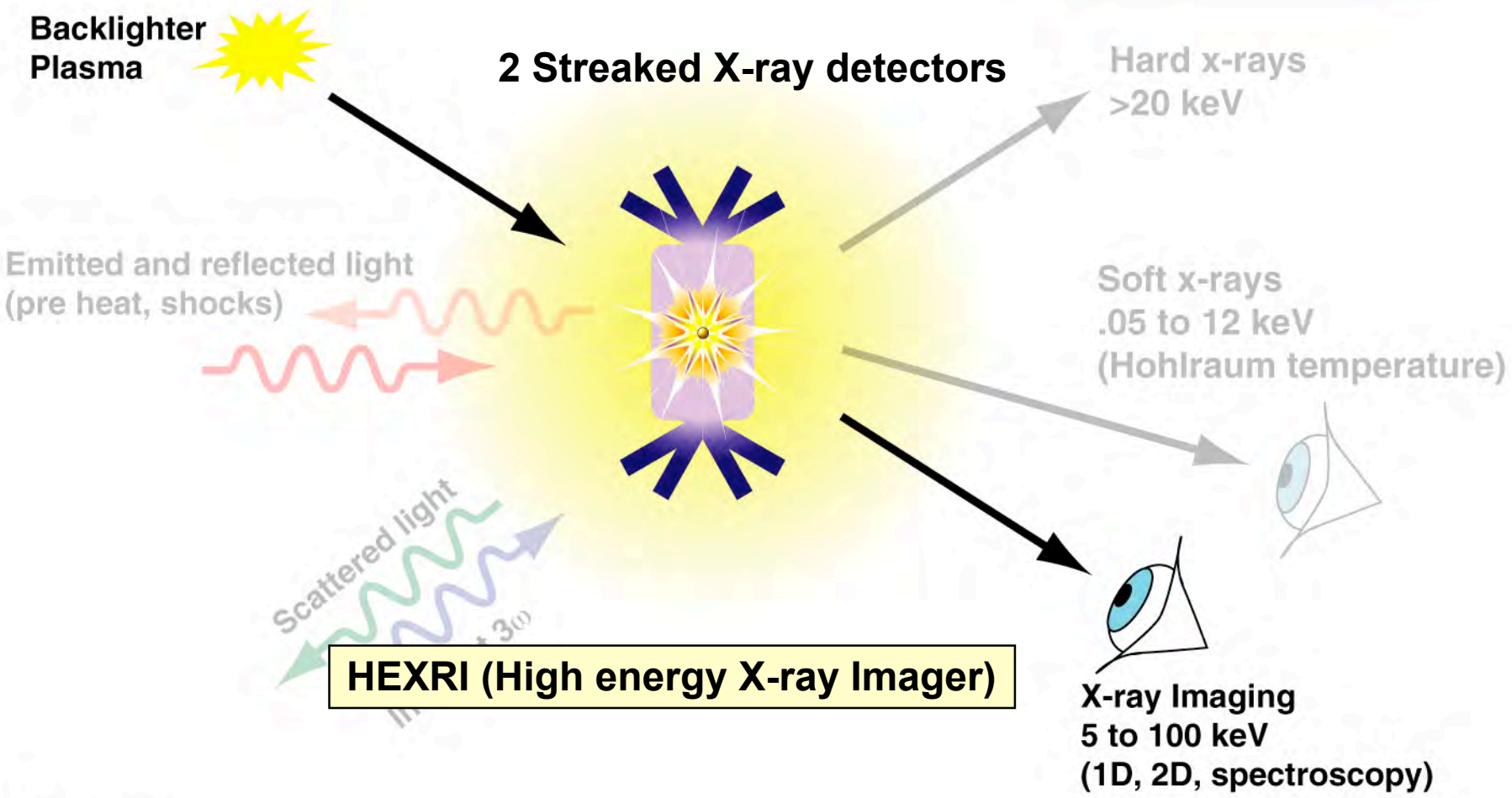
ARC (Advanced Radiographic Capability)
4 segmented High Irradience Beams

X-Ray Diagnostics



High-energy high-intensity missions define the laser requirements

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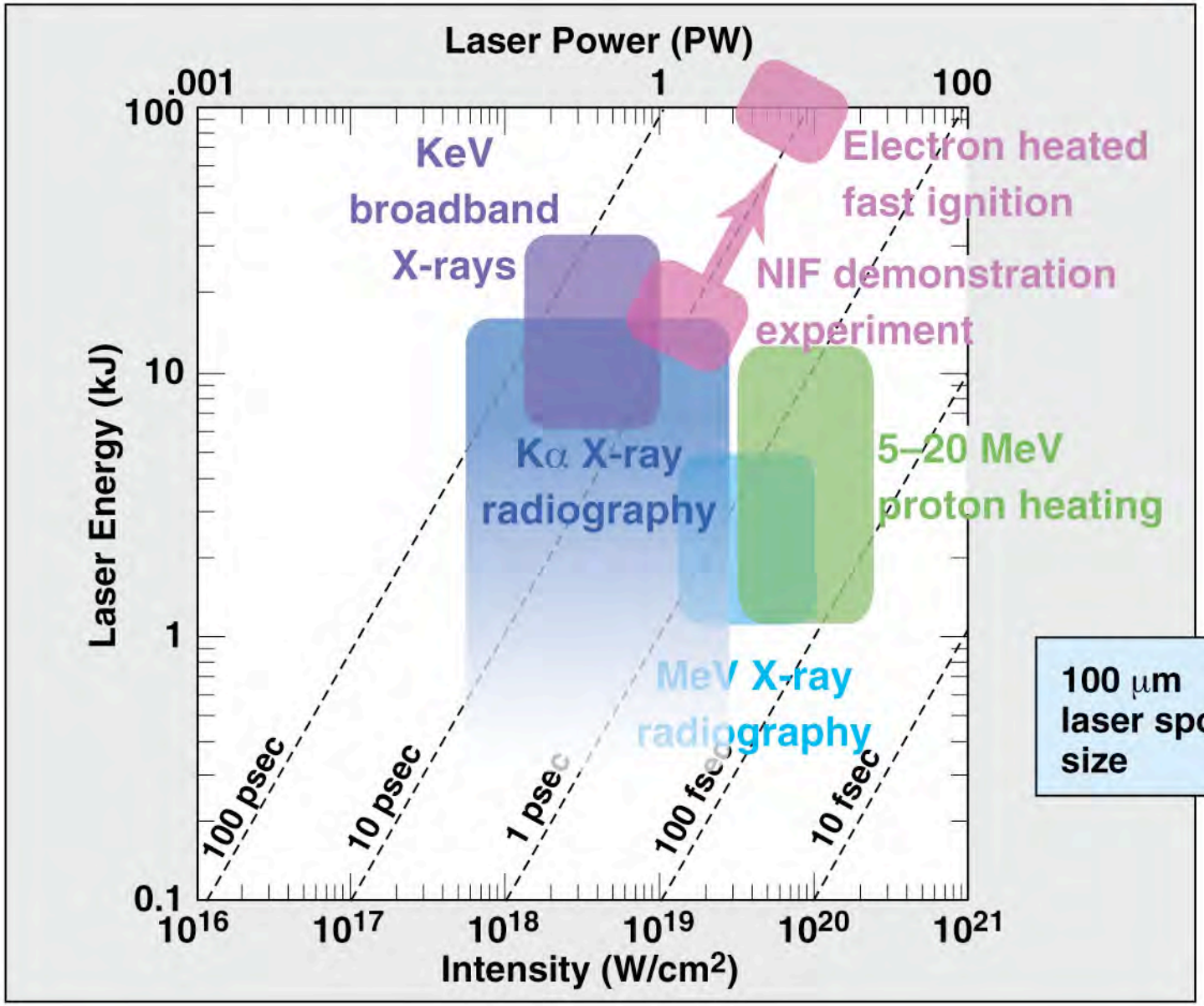

The petawatt beam path in the target bay will be easily switched from the long-pulse beam path

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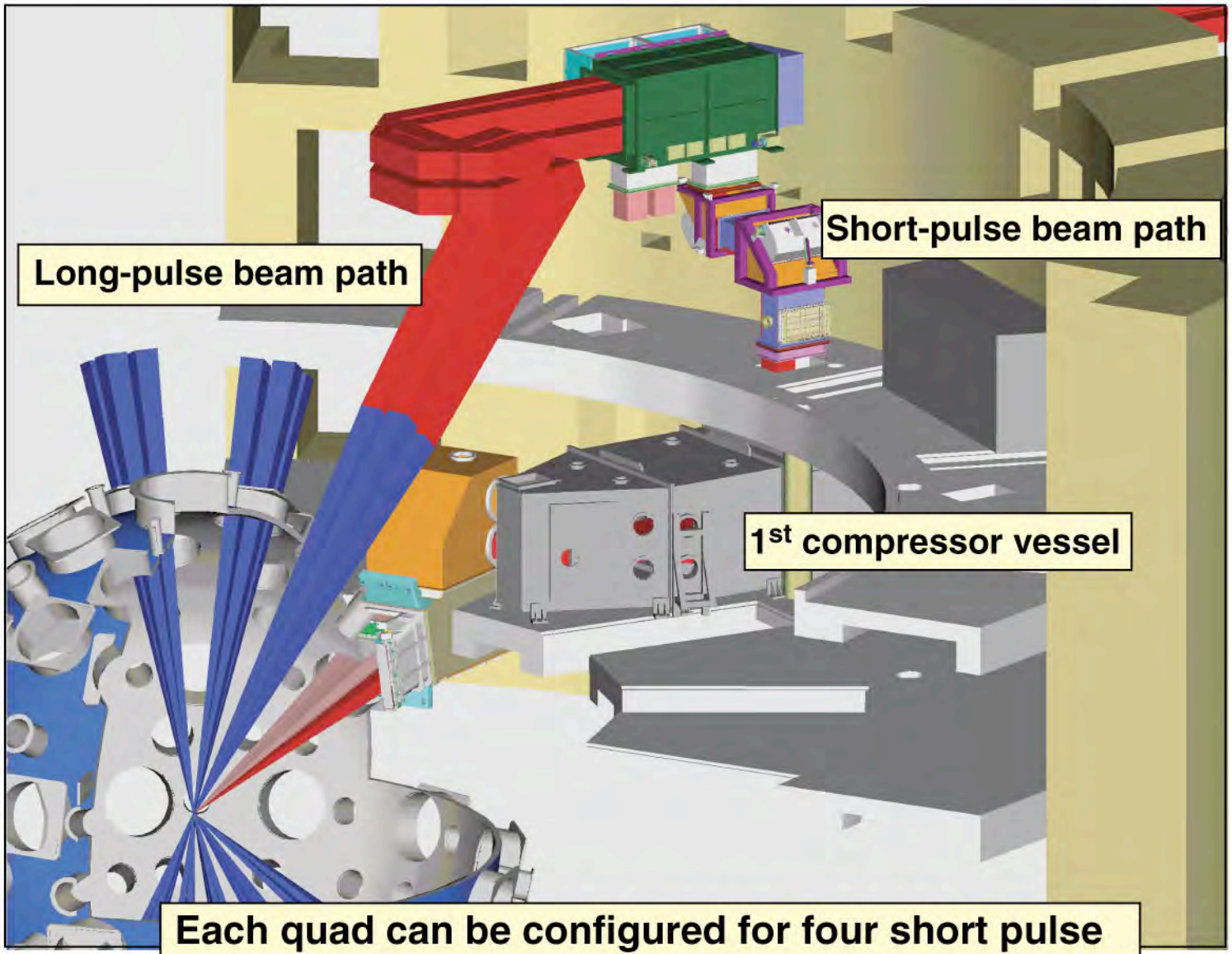

Each quad can be configured for four short pulse multi-kJ beams delivered to target chamber center

A bright, hard X-ray source enables new diagnostic capabilities on NIF

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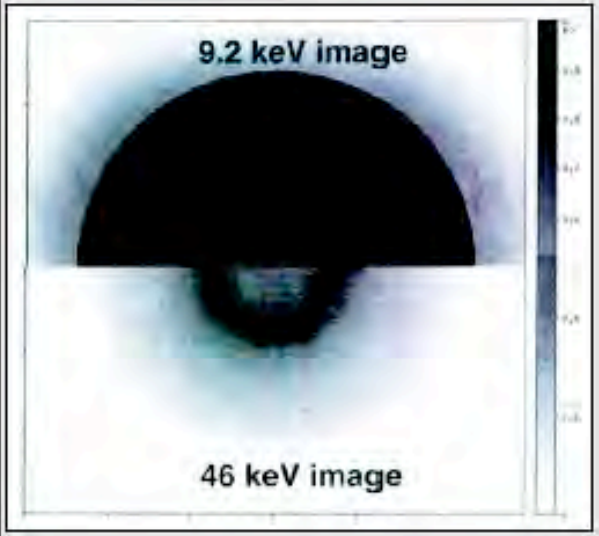
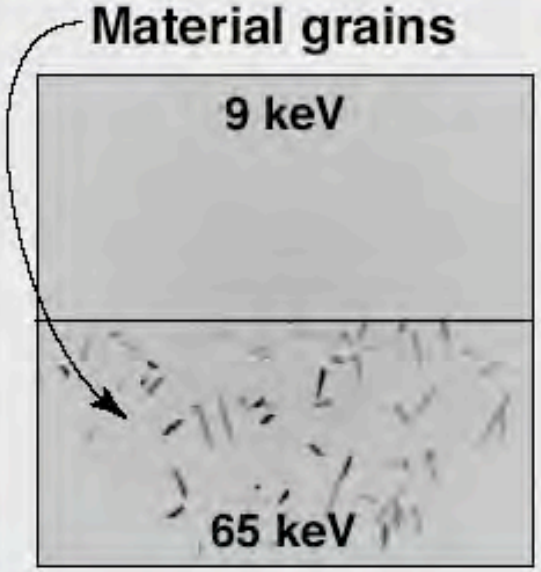
X-ray Radiography Allows Imaging of Dense, High Z Targets



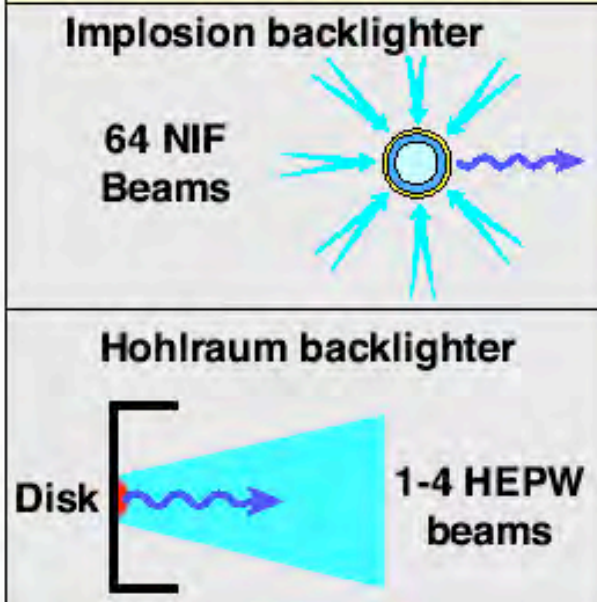
- Hydrodynamics
- Equation-of-state
- Material Dynamics

X-ray Diffraction Allows Study of Grain Effects



- Material Dynamics
- Phase change kinetics

X-ray Absorption Spectroscopy is Greatly Simplified



- Opacity
- Material dynamics

We have made excellent progress in developing these sources for NIF experiments

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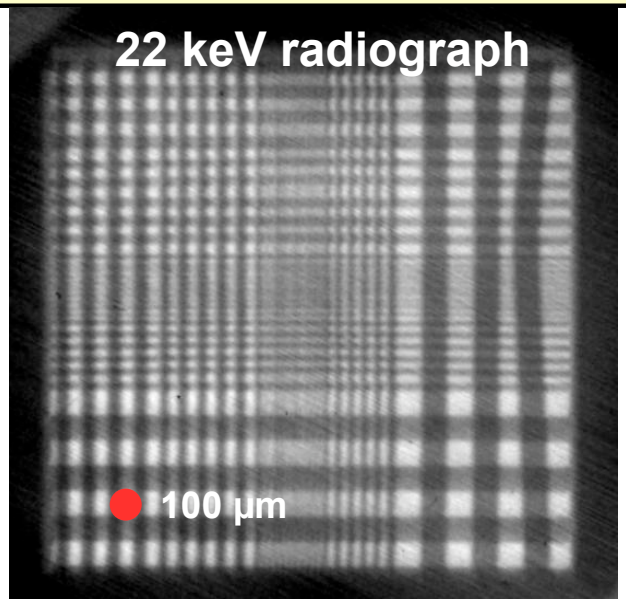
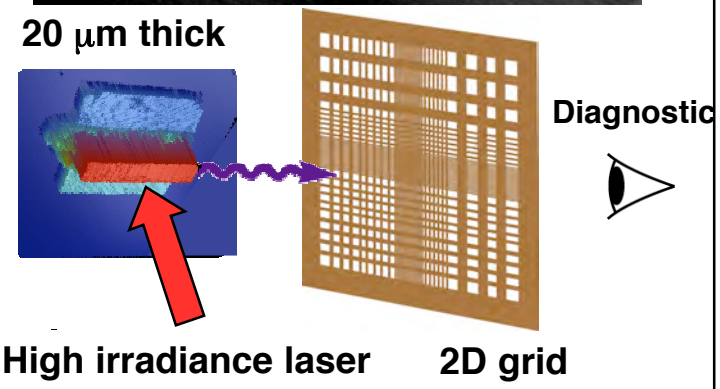
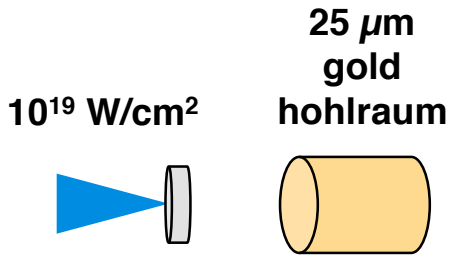
2D Radiography for Hydrodynamics Experiments

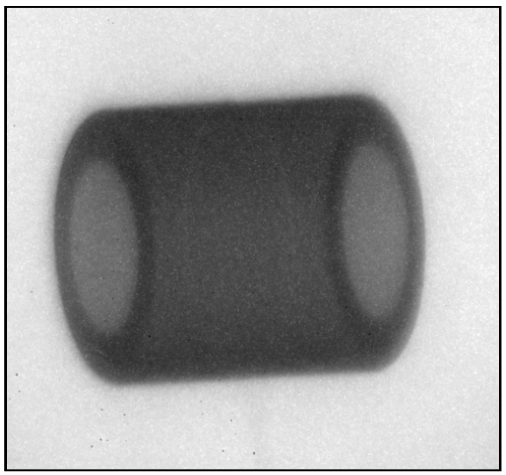




TITAN was used to develop the source and technique

50 keV radiography though a hohlraum





Experiment done on Vulcan

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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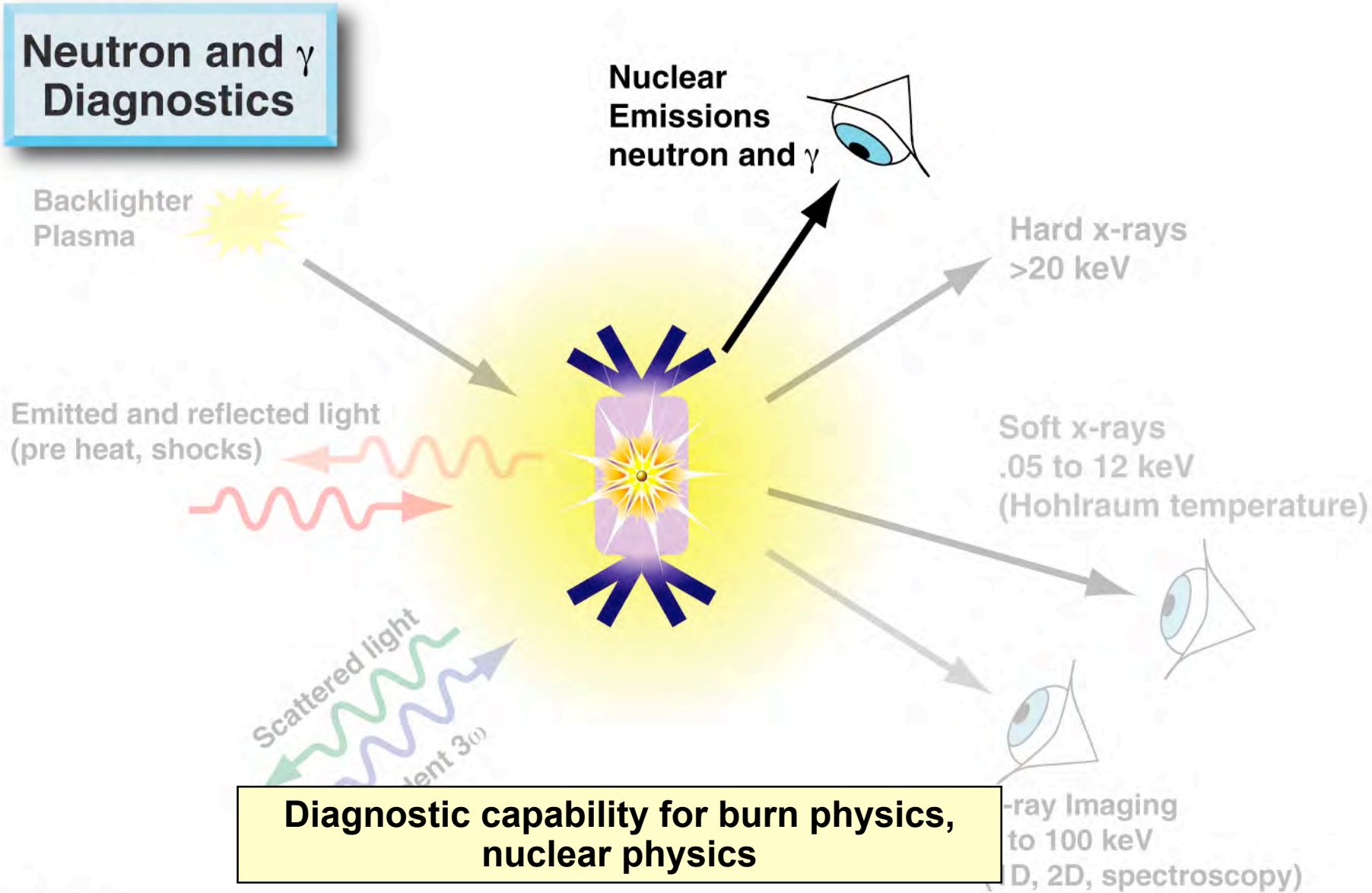

Diagnostic capability for burn physics, nuclear physics

Neutron and gamma diagnostics will be fielded on ignition shots

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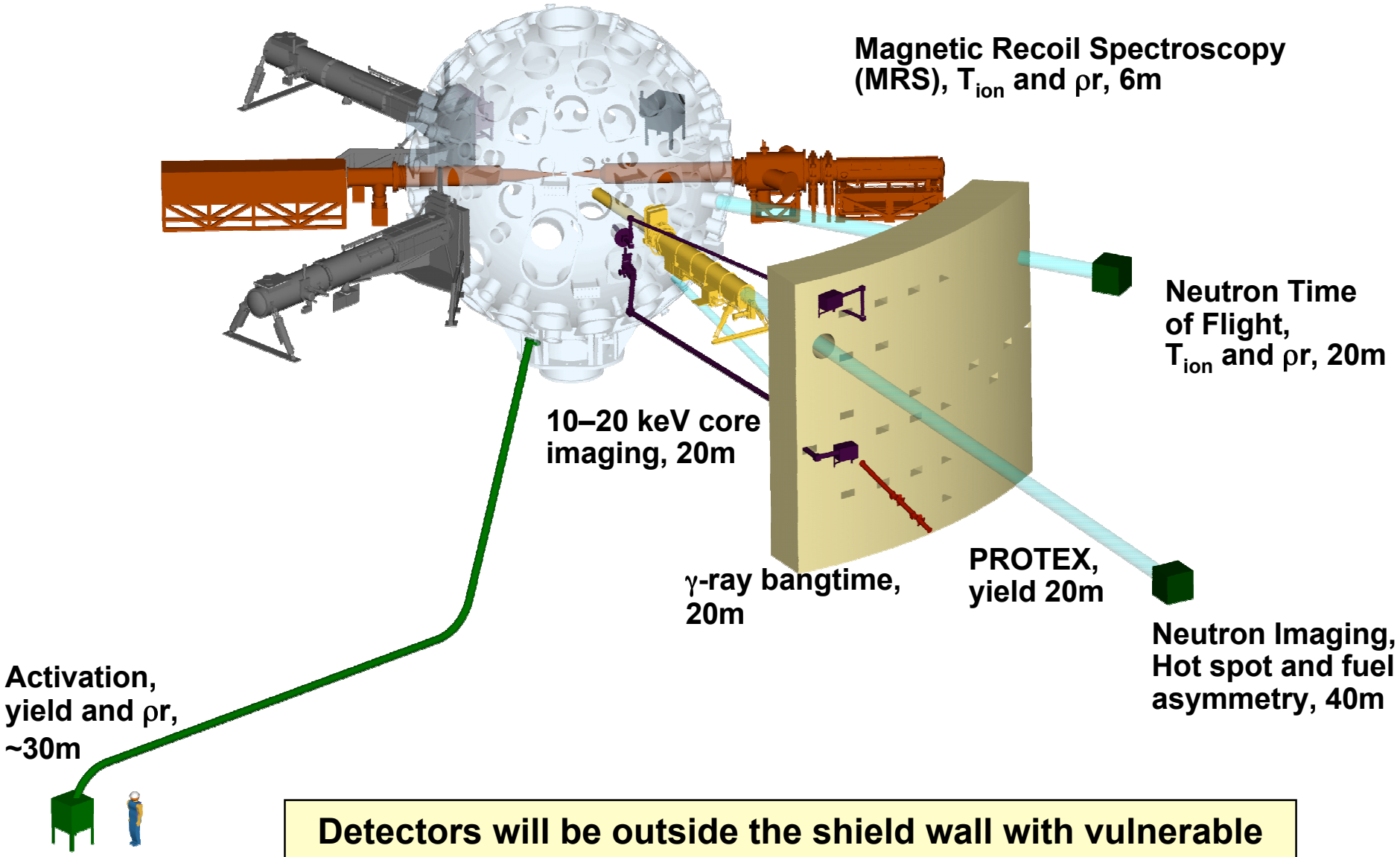

Detectors will be outside the shield wall with vulnerable components shielded

Detectors and sensitive electronics will be located outside the 2m-thick shield wall

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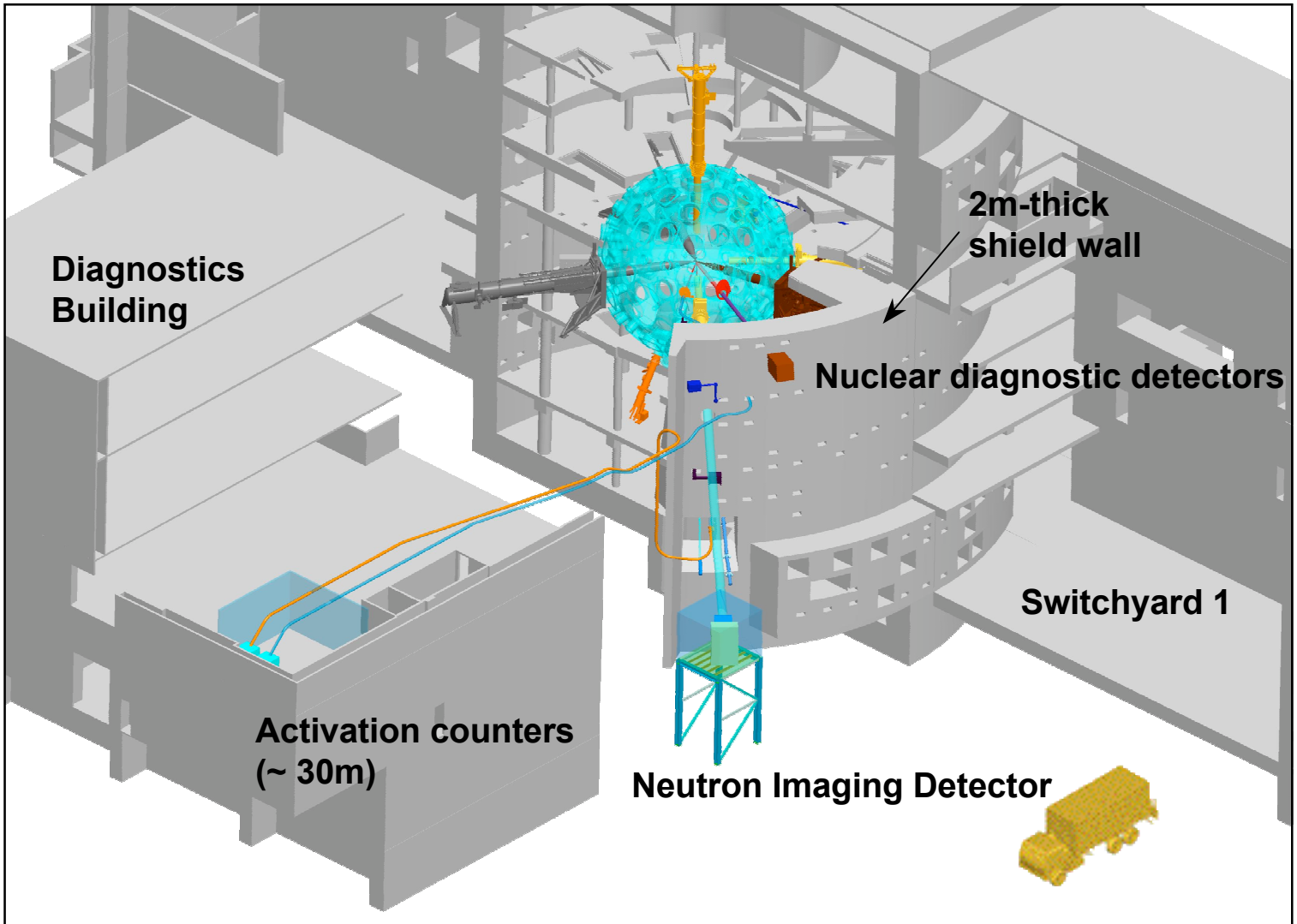

Sensitive equipment (e.g. digitizers or controllers) will be located in shielded bunkers in the switchyards or in the Diagnostics Building

Diagnosing NIC experiments requires detection of different types of emissions < 100 psec, 100 μm

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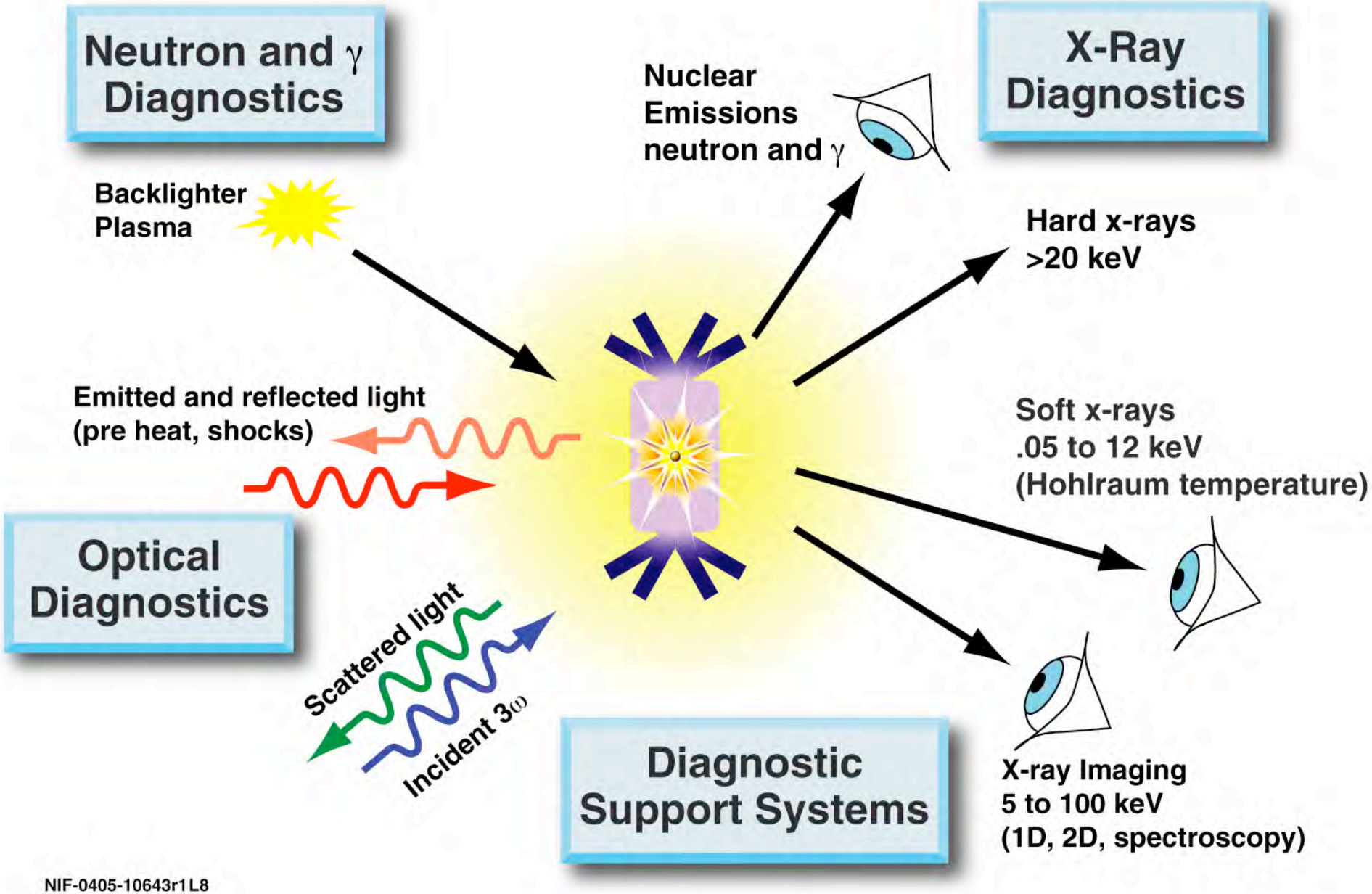

We successfully fielded ~ half of all the types of diagnostic systems on NIF

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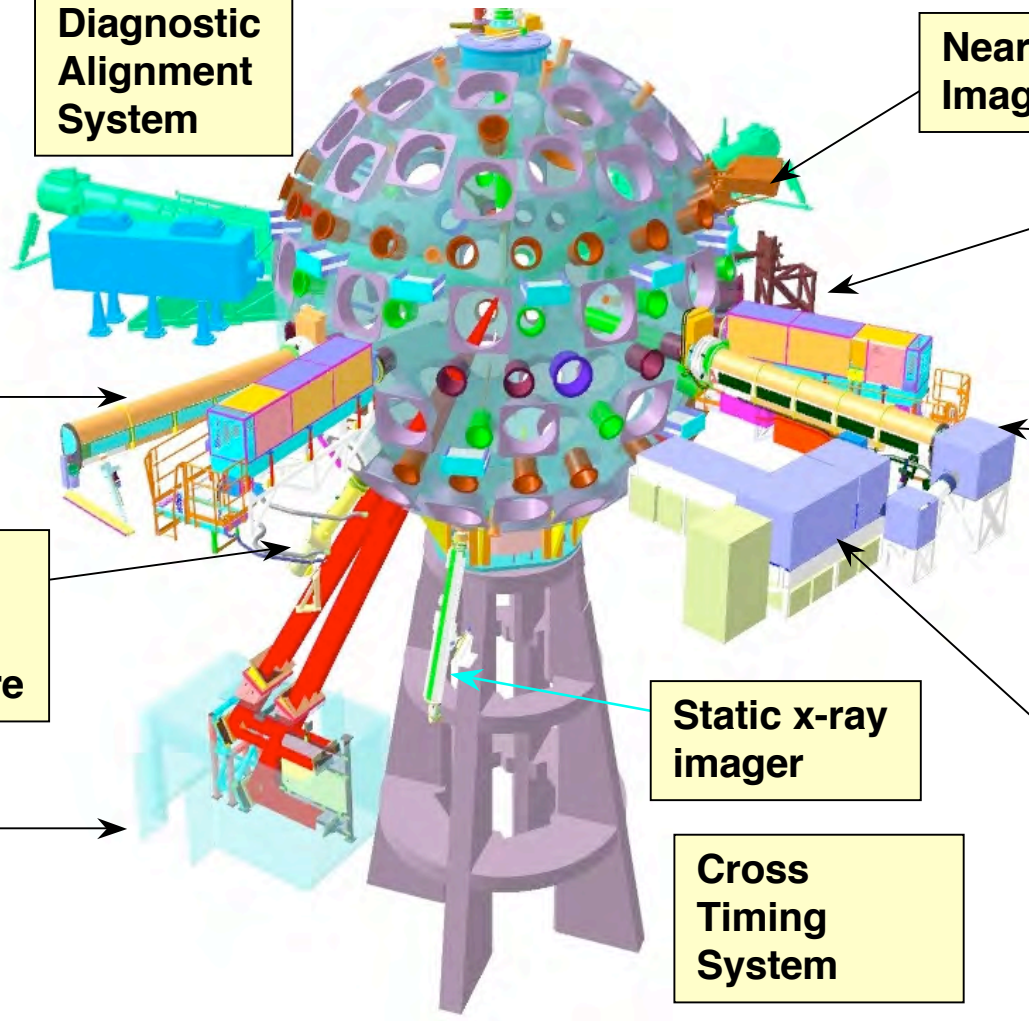

Diagnostic Alignment System

Near Backscatter Imager

Diagnostic Instrument Manipulator (DIM)

X-ray imager

Streaked x-ray detector

FFLEX

Hard x-ray spectrometer

Diagnostic Instrument Manipulator (DIM)

DANTE

Soft x-ray temperature

Static x-ray imager

VISAR

Velocity Measurements

Full Aperture Backscatter

Cross Timing System

Diagnostics returned data 551 out of 577 attempts over a 22 month interval data return was 98% on the last experimental campaign

Diagnostic schedule for NIC

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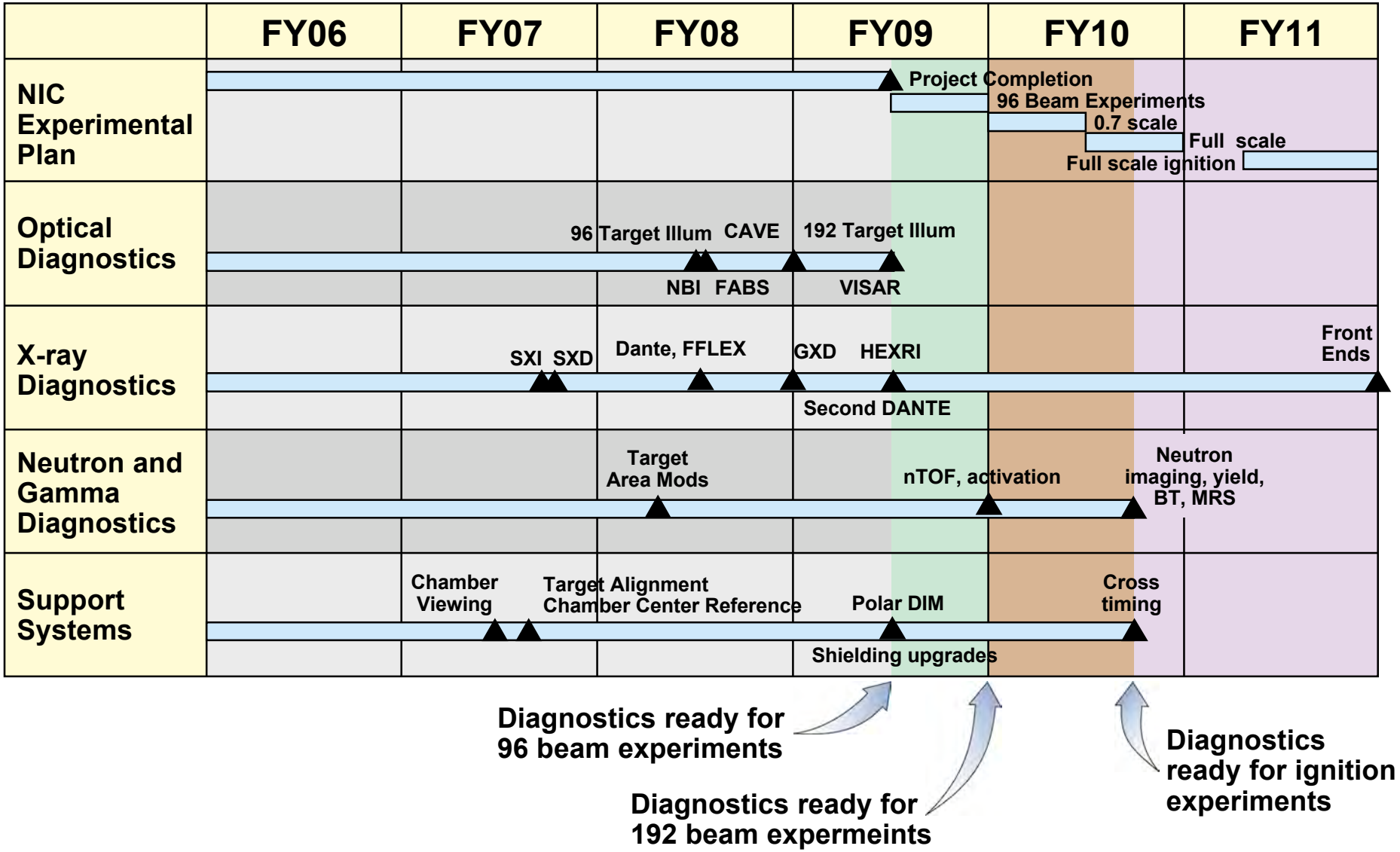

Diagnostic capabilities schedule for science users

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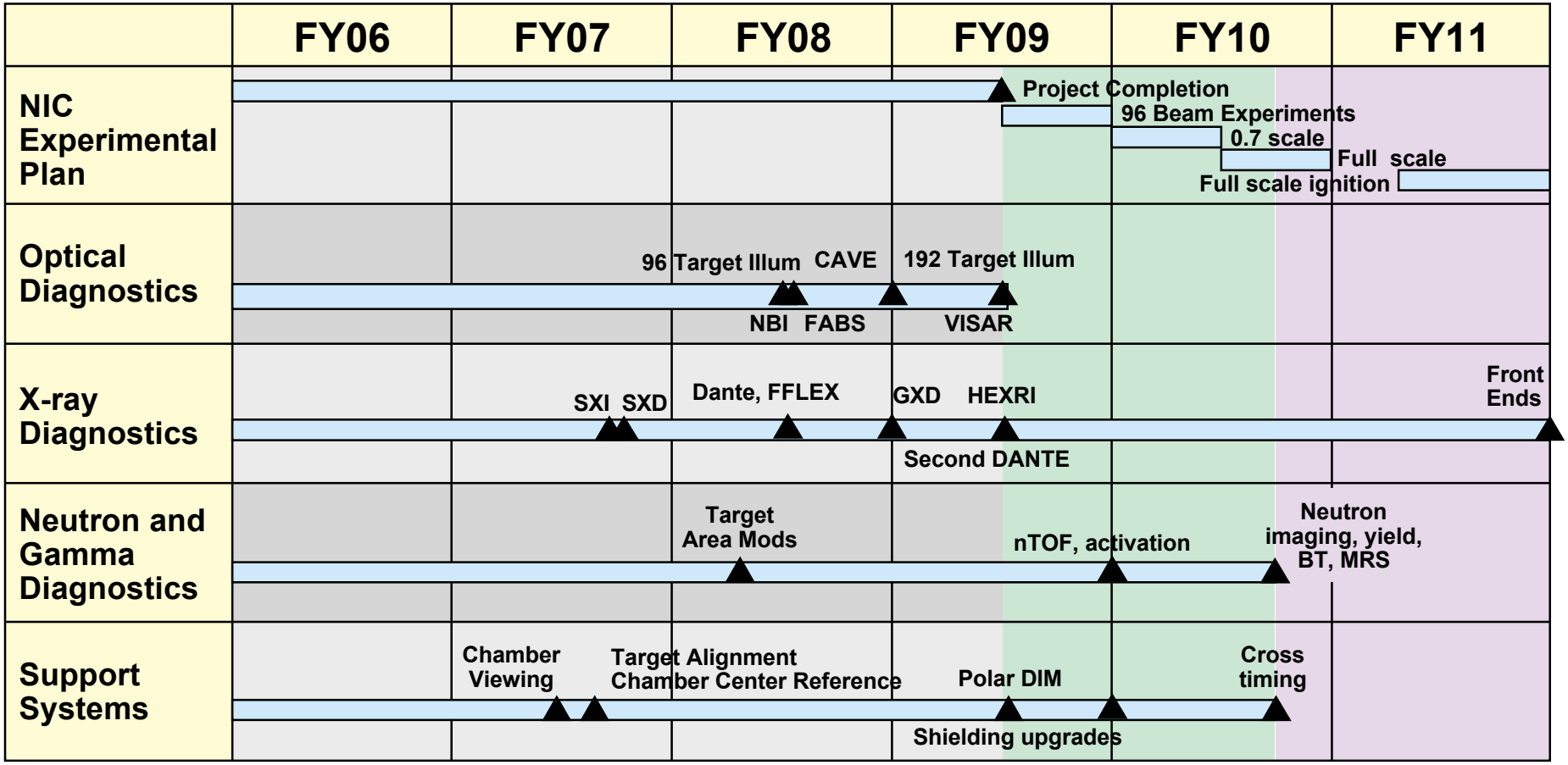

We want to help make your experiments successful on the NIF!

NIF will be the quintessential HED facility

NIF concentrates all the energy in a football stadium-sized facility into a mm^3

Matter Temperature	**>10^8 K**
Radiation Temperature	**>3.5 x >10^6 K**
Densities	**>10^3 g/cm^3**
Pressures	**>10^{11} atm**

NATIONAL
IGNITION
FACILITY

Development of common experimental platforms increases shot availability

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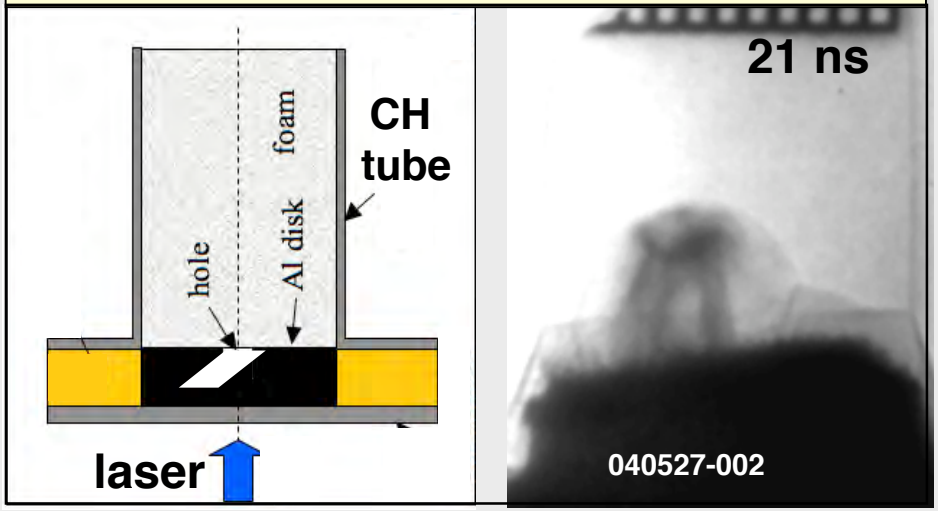
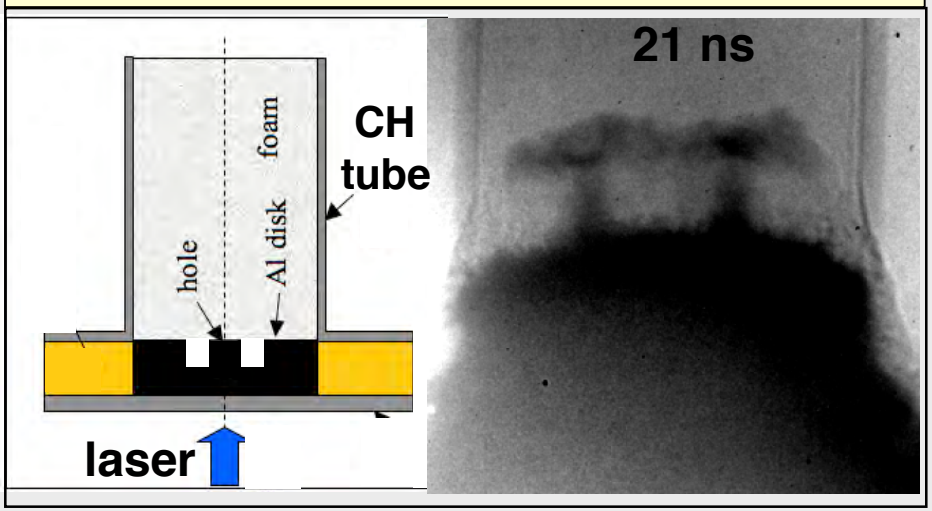
Example: The NEL Hydrodynamics platform was jointly developed and used for different physics experiments

LLNL 3D Experiment



LANL 3D experiment



Most platforms used for NIC and HED are used also for basic science experiments

Capabilities developed for the National Ignition Campaign will be available for science users

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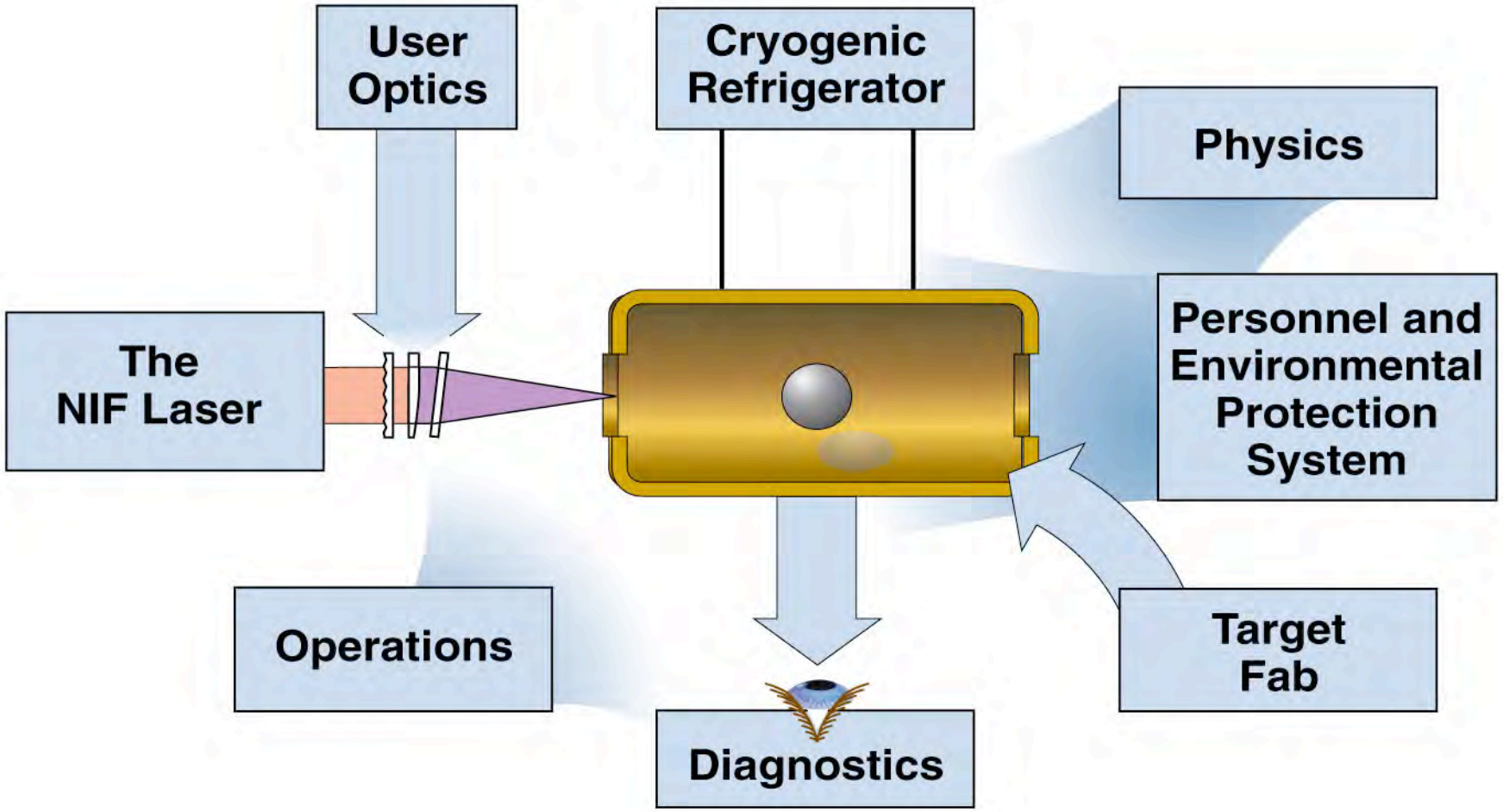

Experimental platforms are developed on supporting facilities and demonstrated on NIF

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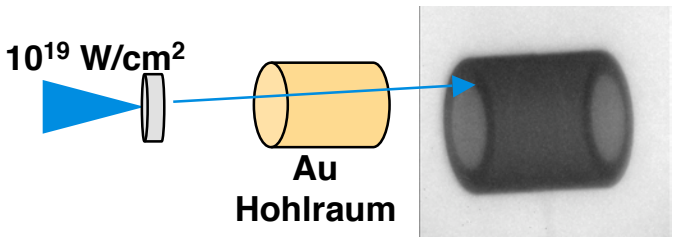
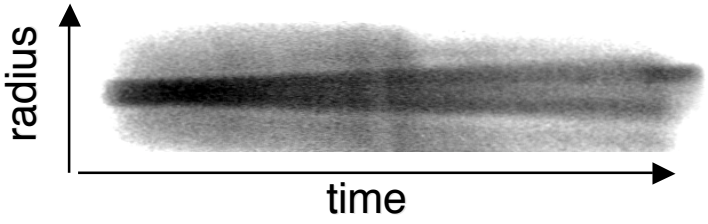
New Techniques - Vulcan



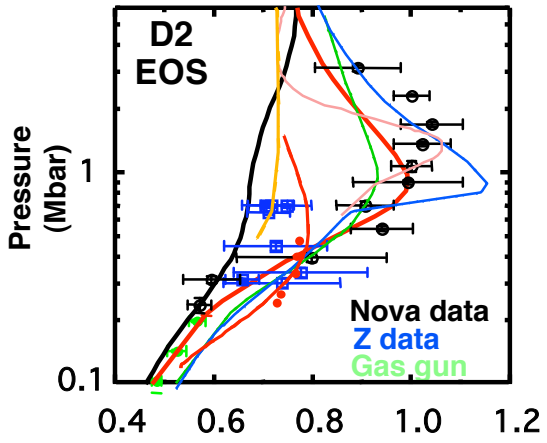
50 keV X-ray radiography

Develop Experimental Platforms - Omega



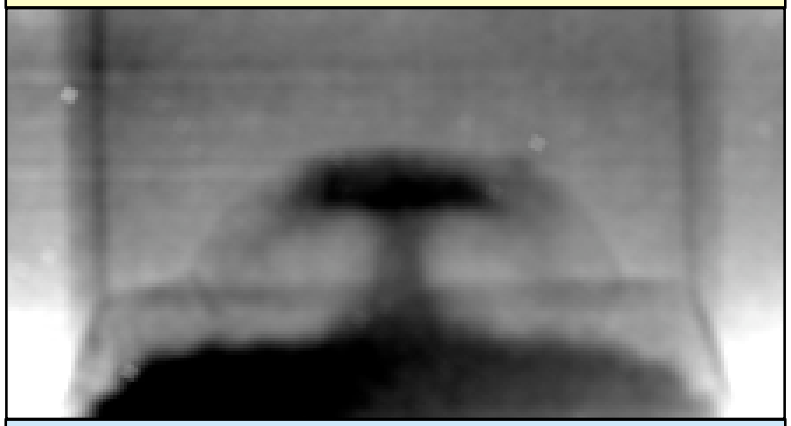
Radiation- Hydrodynamics Platform

Validate Platforms & Techniques - Gas gun, Z, Nova, Omega



EOS of D2

Demonstrate Platform on NIF



Validation
Data on Hydrodynamic Jets

We are developing the material dynamics platform on for NIF in FY10-FY11

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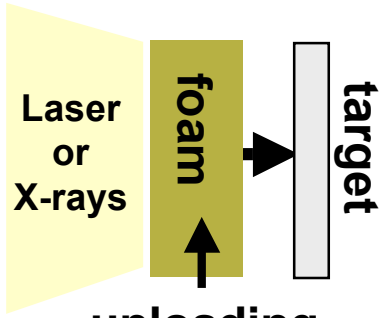
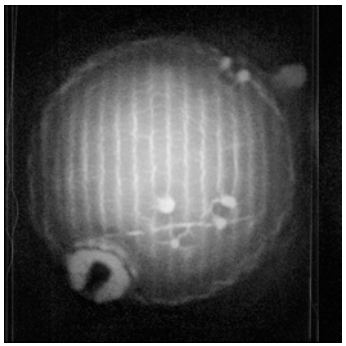
Material Strength and EOS



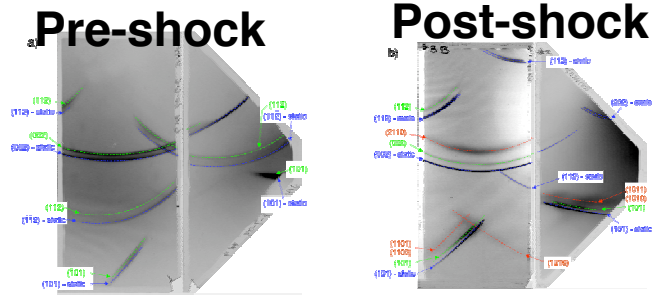
unloading
plasma reservoir



V Strength inferred from RT

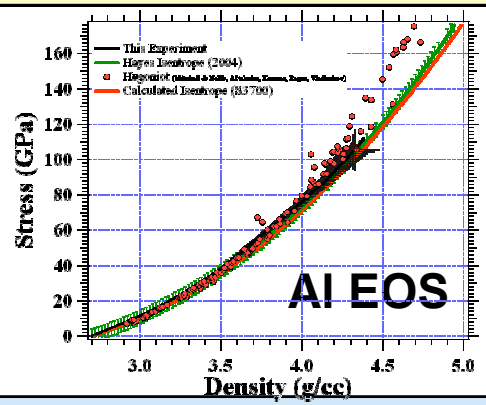
Plasma piston drives a sample shockless to high pressure

Material Phase



Diffraction allows determination of phase changes

EOS Along the Isentrope



Data is consistent with models

We are developing hydrodynamics platforms for NIF in FY11-FY12

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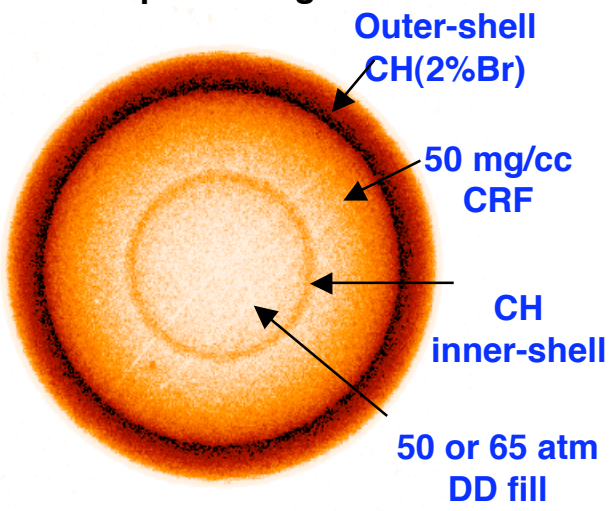
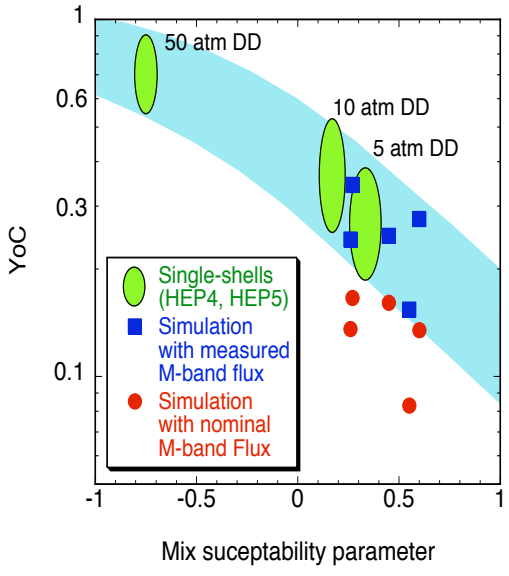
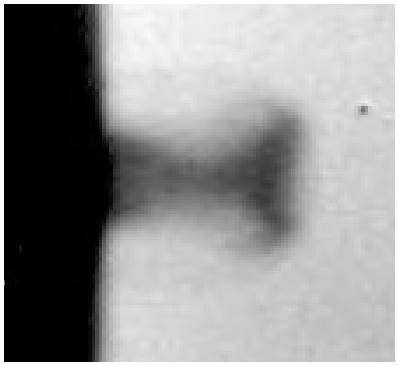
Implosions

Capsule Diagram



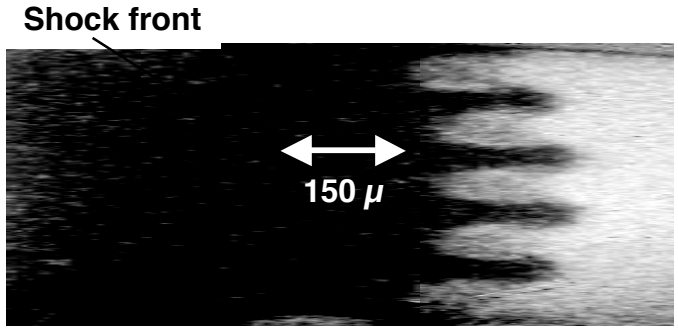


Hydrodynamic Jets



Pure metal foams are being developed for NIF experiments

Hydrodynamic Instabilities



High Mach # RM

We have ~31 types of diagnostic systems planned for NIC through FY11

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Diagnostic System		Types	Status	Location
Optical	Full Aperture Backscatter	2	1 Completed, EMP Upgrade Q4FY08; 2nd Q2 FY09	NIF
	Near Backscatter Imager	1	1 Completed, 2nd Q4FY08, 3rd Q3FY09	NIF
	VISAR	1	Completed, relocate	NIF
	Optical Streak Camera	1	Completed	NIF
	Target Illumination	2	1 Each Completed, remainder Q4FY09	NIF
	Pulse Sync	1	Prototyped, Q4FY08	NIF
	Crystal Alignment	1	Prototyped, Q4FY08	NIF
X-Ray	Dante X-ray Power w/imager	1	Completed	NIF
	Hard X-ray Spectrometer	1	Completed	NIF
	X-ray Streaked Detector	1	Prototyped, 2 Q4FY06	NIF
	X-ray Gated Detectors	2	Completed	NIF
	Front Ends for Detectors	3	4 Prototypes Completed, remainder FY09–FY11	NIF
	Static X-ray Target	2	1 Completed, Gated Q4FY08	NIF
	High Density Target	1	2 Q4FY10, 2 Q4FY11	TITAN, Vulcan
	Hard X-ray Imager	1	Q3FY10	Omega
Neutrons and Gammas	Neutron Time-of-flight w/yield	1	Q3FY10	Nova, Omega
	Neutron Imaging	1	Q3FY10	Nova, Omega, NTS
	Gamma BangTime	1	Q3FY10	Omega, NTS
	Magnetic Recoil Spectroscopy	1	Q3FY10	Omega, NTS
	Activation	1	Q3FY10	Nova, Omega, Z,...
	DT Yield	1	Q3FY10	Omega, NTS
Support	Diagnostic Manipulators	1	2 Completed, EMP Upgrades Q4FY07	NIF
	Diagnostic Alignment	1	Completed, EMP Upgrades Q4FY08	NIF
	Chamber Viewing	1	Q1FY07	NIF
	Cross Timing System	1	Exists, expand in time	NIF
Subtotal		31	21 systems tested on NIF	

We successfully fielded 21 out of 31 types of diagnostic systems on NIF Early Light

System Design Requirements (SDR) are developed through Integrated Experimental Teams with stakeholders, reviewed and put under configuration control

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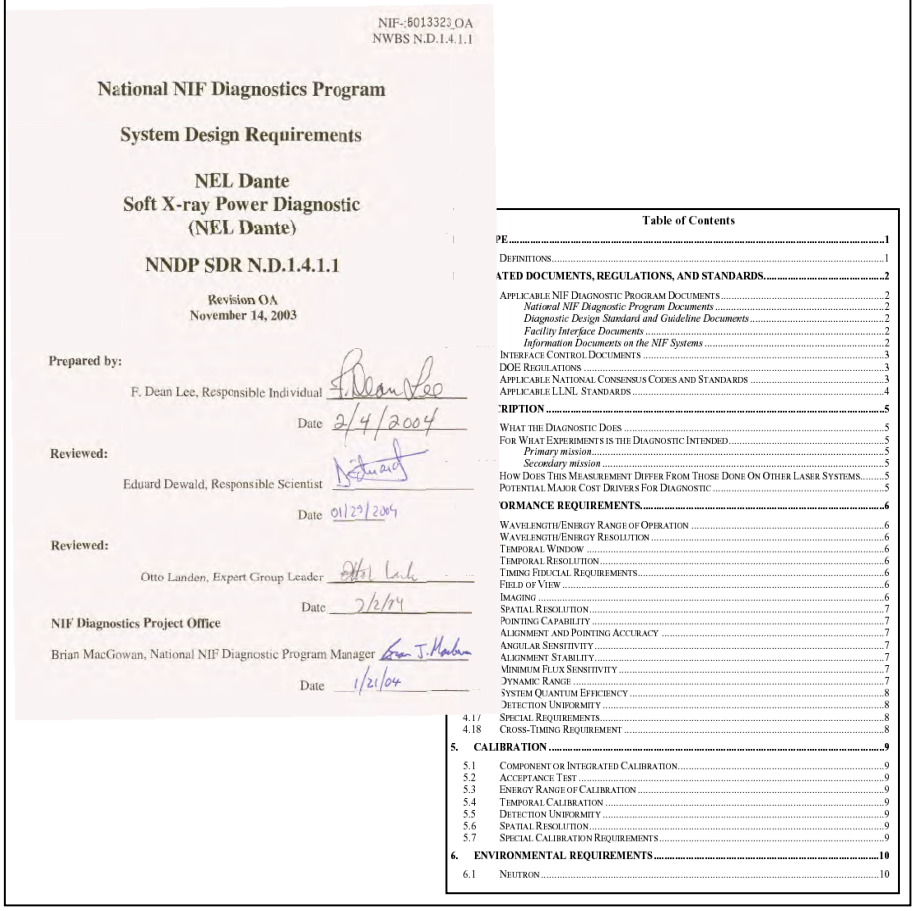
- **Elements of SDR**
  - Functional description
  - Performance requirements
  - Calibration requirements
  - Environmental Requirements
  - Layout and Utility Interface Requirements
  - Operational Requirements
  - Reliability/Availability/ Maintainability requirements
  - Quality requirements

- **There are typically ~ 60 specifications for each diagnostic system**

Example: DANTE SDR



NIF-6013323-OA
NWBS N.D.1.4.1.1

National NIF Diagnostics Program

System Design Requirements

NEL Dante
Soft X-ray Power Diagnostic
(NEL Dante)

NNDP SDR N.D.1.4.1.1

Revision OA
November 14, 2003

Prepared by:

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Date 2/4/2004

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Eduard Dewald, Responsible Scientist

Date 01/29/2004

Reviewed:

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Date 2/2/04

NIF Diagnostics Project Office

Brian MacGowan, National NIF Diagnostic Program Manager

Date 1/21/04

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We are on schedule to complete 90% of all the SDRs this year

Example: Dante Soft X-ray Power Diagnostic SDR

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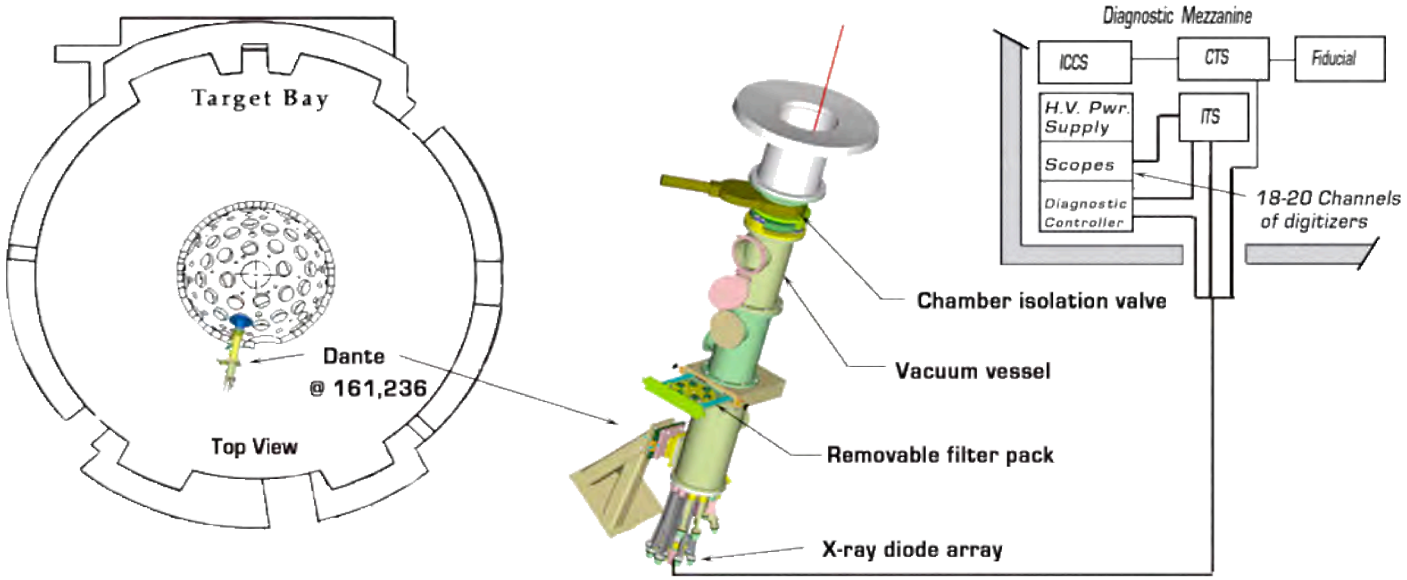
Area	SDR	Section	Requirement
System Description	3.1	What the System does	The soft x-ray power diagnostics measures the absolute soft x-ray emission from a target as a function of time and provides an absolute time history of the radiation temperature inside the hohlraum. The diagnostic also measures "preheat" x-rays in the 2-12 keV range.
Performance Requirements	4.1	Wavelength/Energy Range	The diagnostic shall measure photon energies from 50 eV to 12 keV. The imaging channel should be able to measure photon energies between 500 eV and 3 keV.
	4.10	Alignment and Pointing Accuracy	Pointing accuracy in x and y shall be no worse than 10 mm
Calibrations	5.3	Energy Range of Calibration	The diagnostic shall be calibrated at .05-5 keV with a relative accuracy of ±5% and absolute accuracy of ±10%
Operational Requirements	8.1	Setup Time	After initial installation, setup time shall take no greater than 15 minutes



We have a requirements plan for diagnostic operations at differing levels of yield

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Diagnostic Type	Laser, Energetics, Symmetry, Shock Timing, Ablator Experiments	Convergent shock timing	Ignition Attempts	Ignition
	< 2 1012 DD yield	< 5 e14 TT yield (.5 kJ)	< 1 e16 DT yield (20 kJ)	< 1 e19 DT yield (20 MJ)
Optical	FABS (2), NBI (3), VISAR			
X-Ray	DANTE, FFLEX, GXD, SXD, SXI (2)	SXD (2)	HEXRI	
Neutron & Particles		nToF	nTOF, MRS, Activation, GBT, Protex, NI	Activation
Other	DIM (2), OPAS (2), CTS	DIM (2), OPAS (2), CTS	DIM (2), OPAS (2), CTS	
# of diagnostic systems on a given shot	~ 16	~ 7	~ 12	~ 1